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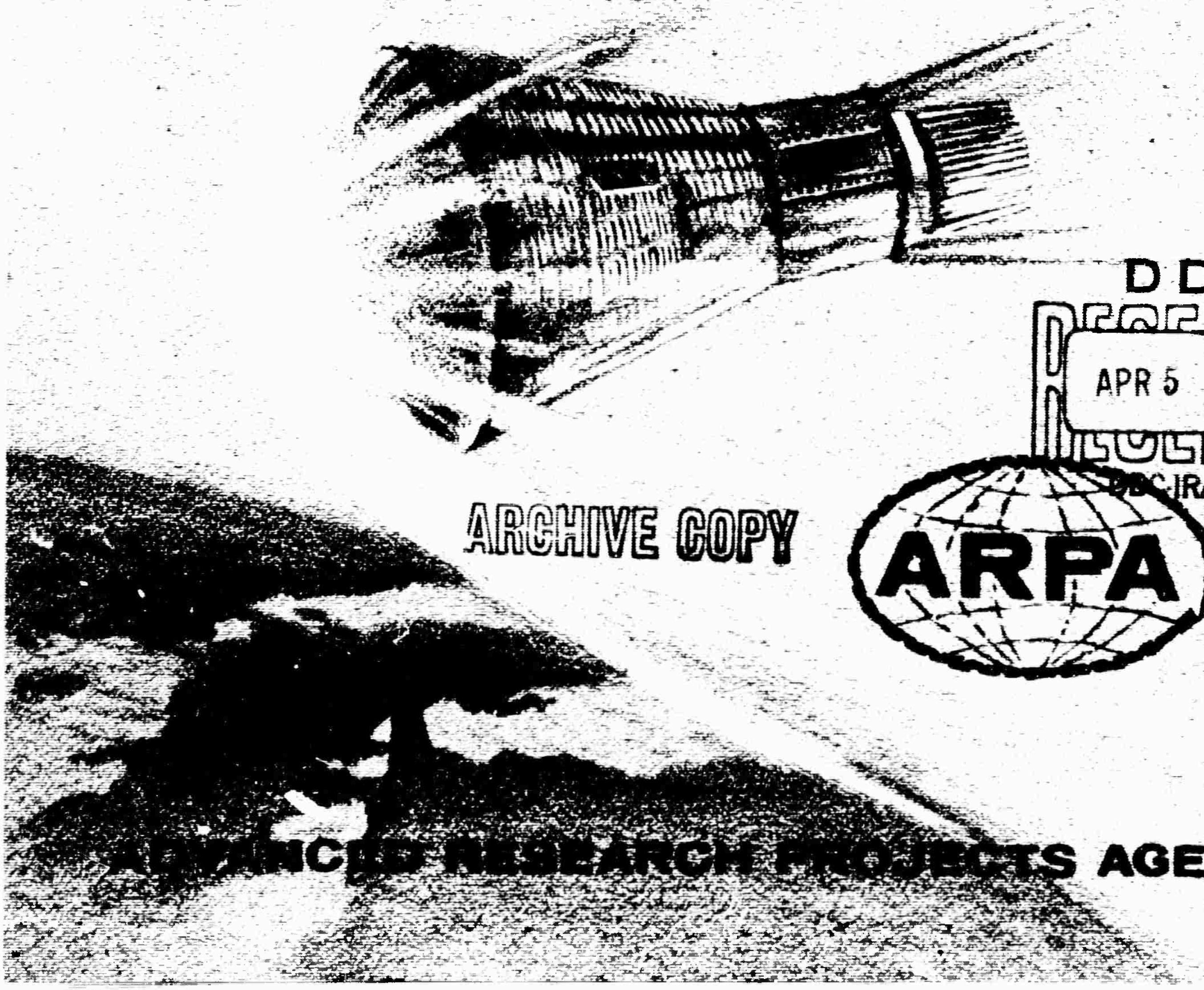
OBSERVATIONS OF THE NEAR WAKE REENTRY PHENOMENA...

BY THE MERCURY ASTRONAUTS

- M. Scott Carpenter
- L. Gordon Cooper
- John H. Glenn
- Walter M. Schirra, Jr.



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OBSERVATIONS OF THE NEAR WAKE REENTRY PHENOMENA

BY THE

MERCURY ASTRONAUTS

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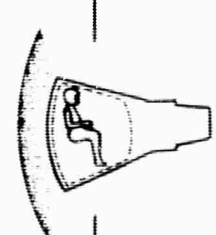

L.Gordon Cooper

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The authors are also very much in debt to Mrs. Lois Catha of ARPA for her valuable efforts in the preparation and editing of this report and to Mr. Fred Koether, ARPA TIO, for his assistance in its publication.

I. INTRODUCTION

A body flying at hypersonic speeds through the earth's atmosphere leaves a trail of hot gas behind it with temperatures as high as 4000 - 5000°K. At these temperatures the gas becomes optically visible from pure air radiation, as well as from contaminant radiation from the material which may be ablated off the reentry vehicle heat shield. High electron densities also occur and the near wake becomes a backscatterer to radar. Both as a passive radiator and active scatterer, the wake is one of the most prominent observables over a large part of the trajectories of missiles reentering the atmosphere.

An extensive research effort has been undertaken by ARPA and other government agencies to define the properties of the wake for various body shapes, flight conditions, etc. General reviews of the current status in the understanding of wake phenomenology are available in a number of publications, e.g., Refs. 1 - 6. One of the most difficult aspects of the problem has been the prediction of properties immediately behind the body. This base region is important because 1) for certain types of vehicles it may provide the only region of gas observables and 2) the end of this region -- the

rear stagnation point -- interfaces with the beginning of the wake. Thus, the solution for fluid properties in the base region provides the initial conditions for the downstream wake calculations. As shown in Figs. 1 and 2a this so-called base and "neck" region is where the flow closes behind the body and forms a contracted viscous core. This core subsequently diffuses outward in the downstream direction and entrains the surrounding air at a rate which is roughly proportional to the cube root of the axial distance for axisymmetric bodies. For some body shapes and atmospheric conditions, the initial conditions for such properties as temperature and ionization level have only a small effect on the downstream property histories. Thus, results of wake calculations can be accepted as fairly reliable. This is the case for most blunt bodies where the larger amount of flow energy is initially exterior to the viscous core. However, for some conditions the initial values for the wake calculations are crucial to the downstream history. In these cases knowledge of the "neck" region is important.

Experimental studies of the flow detail in the base region would prove very useful and at the present time such programs are being carried out in a number of wind tunnels and ballistic ranges across the country.[15, 26-28] However, it is difficult to support a

three-dimensional vehicle and to make point measurements which do not perturb the base flow being studied. In an attempt to determine flow properties around a full-scale reentry vehicle, ARPA has initiated an on-board measurements program in which flow-measuring instruments are mounted directly on a reentry vehicle and their readings recorded and telemetered for later study.

With this background and interest, it was noted in newspaper accounts that several of the Mercury Astronauts mentioned what they called the "fireball" effect which they were able to observe through a rearward-facing window in their capsules. The present authors felt that a discussion with the Mercury Astronauts concerning their observations might be useful. Hence, an inquiry was sent to NASA by Dr. Charles Herzfeld, Deputy Director of ARPA, requesting such a meeting. The request was granted and a conference took place on October 18, 1963, at the Manned Space Flight Headquarters in Houston, Texas. In spite of extreme demands on their time, the four Mercury Astronauts who had orbited, John H. Glenn, M. Scott Carpenter, Walter M. Schirra and L. Gordon Cooper took part in the conference.

The procedure adopted for the conference on the suggestion of the Astronauts was that first, each described his visual observations

during reentry and then next there was a general discussion comparing impressions of the flow field geometry and coloration. The Mercury Astronauts were not debriefed on their reentry observations at the time of their flight. This was evidently the first time that all four had discussed together in detail these observations. It must be remembered that the conference was based on recollections of events which took place from 5 to 20 months prior to the discussion.

Detailed descriptions of each flight have been presented by NASA in Refs. 7 - 10. The preparation for and the flight itself are set forth and the transcripts of the Astronauts' air-ground communications are also presented in these references. Related to the present interest, some exterior wake radar measurements were made from the ground during the reentry of Col. Glenn's capsule using a meteor radar placed on the island of San Salvador.[11]

The present report attempts to be self-contained. Section II gives a brief review of base flow analyses and experimental laboratory efforts; in Section III the general test conditions and the geometry relative to the observer in the capsule are detailed. In Section IV, each Mercury Astronaut's visualization of the flow field as a function of trajectory position is described. In Section V, the general aerodynamic conclusions by the authors are set forth.

II. REVIEW OF THE BASE-FLOW AND NEAR WAKE PROBLEM

The interaction of the core of a separated flow with an inviscid free stream through a mixing layer remains one of the most difficult and as yet unresolved problems of aerodynamics. Accurate prediction of the properties in the wake of a re-entering body depends on accurate knowledge of the initial conditions for the wake calculations at the end of the base region, "the neck," see Fig. 2.

Complete laboratory simulation of the important reentry conditions for the base problem throughout the whole reentry corridor is not presently possible. Such crucial questions as what is the peak neck temperature and is the temperature distribution across the neck unimodal or bimodal are yet to be answered. Further, laboratory diagnostics are not completely satisfactory for answering such questions.

*It has been understood for some time that the neck conditions (and the entire near wake geometry) are determined by the complex interaction of the inviscid "outer" flow and the viscous "base flow." The Chapman model[12] of this interaction has provided the most

*Based on a review of the near wake region work to this date by R. Weiss, Avco Everett Research Laboratory.

useful starting point for analytical solutions and experimental correlations of near wake phenomena. Figure 2a illustrates the description of the flow field. The body boundary layer separates at the shoulder and is deflected towards the axis by the low base pressure, re-attaching at a rear stagnation point. A separated, recirculating flow region is thereby created which then achieves a velocity determined by an equilibrium of shear forces on the "base" and "dividing streamline." Particular significance by all workers is attached to the dividing streamline, which in Chapman's model is assumed to undergo an isentropic recompression to the pressure imposed by the inviscid flow immediately behind the trailing shock. The stagnation pressure reached by the dividing streamline depends on its static pressure and velocity. The former is assumed to be determined by the outer inviscid flow, and the latter by constant pressure and constant energy mixing of the "free shear layer" (the separated body boundary layer) with an infinite reservoir of stagnant air (Fig. 2b). In the Chapman model, the free shear layer is assumed to have zero initial thickness, and the solution obtained is true only asymptotically at large distances from separation. The Chapman near wake flow description is summarized by these assumptions:

1) zero initial boundary layer thickness at separation

2) no distortion of the boundary layer as it expands around the shoulder

3) "boundary-layer" flow in the free shear layer

4) constant pressure and constant energy laminar mixing in the free shear layer

5) zero "coupling" between free shear layer and recirculatory flow

6) isentropic recompression at the neck

7) zero heat transfer and mass addition at the base

In addition to these, the "steadiness" of the flow has been a generally accepted assumption. This is because of the indicated stability from linear stability theory of the free shear layer at hypersonic speeds.

The ability of the Chapman theory to predict the basic characteristics of the near wake behind representative bodies can be estimated from data shown in Fig. 3 ("oblique shock" and "isentropic recompression" refer to the inviscid flow limit conditions that bracket the actual behavior). While the theoretical results have no Reynolds Number dependence, it is apparent that the data do.

Initial attempts by Denison and Baum[13] to improve these results have eliminated the first assumption listed above. They have

obtained numerical solutions of the growth of a finite-thickness free shear layer. The dividing streamline velocity was shown to be a sensitive function of shear layer length. Thus, the inviscid-viscous flow coupling becomes more complex. These results are labeled "theoretical laminar flow" in Figure 3.

Since the dividing streamline velocity depends on the initial mixing rate at the shoulder, careful consideration of the expanded velocity profile is necessary. Hromas and Lees [14] recently investigated this problem and found that at hypersonic speeds the velocity profile "flattens" upon isentropic expansion around the vehicle corners. Dewey[15] examined the effect of various expanded profiles on the free shear layer development. He found that the initial shear and velocity on the dividing streamline are larger than the results obtained when this effect was not included.

Treating the non-isoenergetic free shear layer, Denison and Baum[16] have used a Crocco Integral energy solution in conjunction with the isentropic recompression of the dividing streamline. The results show that the neck pressure and enthalpy are strongly influenced by the core temperature. In more recent work, King and Baum[17] have attempted to determine the core temperature by energy balance calculations. Again, assuming no coupling with the recircu-

latory flow, the enthalpy profile (and atom concentration profiles) was determined at the neck and a core temperature chosen so as to conserve energy between shoulder and neck (that is, to satisfy the assumption of zero base heat transfer). There is still considerable uncertainty about the core temperature. For the purpose of comparing the compressible solution with the available full-scale data, both "hot" (free stream stagnation temperature) and "cold" (free stream static temperature) theoretical results are shown in Fig. 4.

The validity of the boundary layer equations in the free shear layer of a hypersonic, sharp-shouldered body has recently been questioned by Kubota,[18] who points out that one effect of the shoulder expansion is the thickening of the separating boundary layer. This would result in appreciable transverse pressure variations, and adjustments to zero gradient boundary layer solutions would be required.

The assumption of the isentropic recompression on the dividing streamline has also received attention recently from Lees and Reeves.[19] They piece together a free shear layer recompression solution with an already known re-attachment velocity profile (obtained from shock wave-boundary layer-interaction theory).

Numerical solutions for pressure variations from the base to the inviscid value (downstream of the neck) have been obtained by this method. The solution method is essentially an integral one, and an "averaged" solution for the neck region is obtained. This approach is now being extended back to the base. Another effort to calculate the recompression region is that of Weiss[20] who uses a linearization of the equations of motion by expansion in Reynolds Number. S. Cheng[21] has investigated allowable streamline shapes around the stagnation point. It should also be noted here that Erdos and Pallone[22] have obtained a semi-empirical solution to the base flow geometry by extending well-known results of flow separation and re-attachment on flat plates with forward facing steps. While such solutions correlate the experimental data shown in Fig. 3, the physical basis for this extension is uncertain.

The importance of the recirculation region in determining the fluid dynamics and chemical composition of the near wake has been indicated by H. Cheng.[23] For a complete understanding of the mechanism which controls the steady-state base flow geometry, the role of the recirculation region appears to be crucial. King[24] has recently completed a rough theoretical calculation of heat transfer to the base with an "inviscid core" model of the recirculation region.

There are at least six laboratory experimental programs in connection with the determination of the neck enthalpy ratio. Basic information on the near wake velocity and pressure fields of two-dimensional bodies have been obtained recently by Dewey[15] at a Mach number of 6.04 (GALCIT Tunnel) to check many of the theoretical assumptions described above. A laboratory experiment has been carried out by Muntz and Zempel[26] to determine the near wake density distribution with an electron beam technique. Relying on the Denison and Baum theory for the flow geometry and pressure field (and using the measured core density instead of the unknown core temperature), the neck enthalpy ratio for a 7° cone at M = 17.5 and Reynolds No. /inch = 1.28×10^{5} was estimated to be 0.13 - 0.18. The theoretical result for these conditions from Denison and Baum is like 0.40. The factor of two (2) difference in enthalpy ratio may be like orders of magnitude in terms of electron concentrations. A long-range program of aerodynamic testing of spheres and cones has been undertaken by Dayman[27] to study near wake properties over a range of free-stream conditions. Utilizing a free-flight technique to eliminate support interference problems, this series will attempt to supply much needed data on base pressures and heat transfer. Finally, Bogdonoff (Princeton) has a magnetic support

for his hypersonic tunnel and can investigate base flow effects independent of body support problems. He is now proceeding with an experimental research program on the base region.

From this review it appears that three essential contributions are needed at this time:

1) an analysis which includes the effects of the re-circulation region

2) an experimental determination of the degree of steadiness of the base region

3) an experimental determination of the base flow temperature distribution

At the high speeds encountered during orbital reentry, the hot gas becomes luminous and colors the base region and near wake. Thus, the flow field becomes colored as if by dye and the flow patterns could be observed by an observer fixed in the vehicle coordinates. The Mercury Astronauts were in a unique position to perform such observations. The Astronauts, of course, had many crucial tasks to perform in order to bring their capsules safely back to Earth (see Pilots Reports, Refs. 7-10 and Section IV). Thus, each of the Astronauts was not able to view the near wake over all of the reentry trajectory of his capsule. However, sufficient observation was possible to provide information of value.

III. DESCRIPTION OF THE MERCURY SPACECRAFT AND GENERAL TEST CONDITIONS

A. General Characteristics

The Mercury vehicles used for the four orbital flights were all of the same design and construction with some minor variations which will be mentioned later. Fig. 5 shows the general configuration of the spacecraft including the retropackage. Fig. 6 shows the makeup of the outer surface of the spacecraft in the reentry configuration (i.e., with the retropack jettisoned). The only ablating material is that of the heat shield, a glass fiber-phenolic resin composition. The antenna fairing, separated from the cylindrical section by a Vycor (fuzed quartz) spacer, forms a bicone antenna for VHF and HF voice communications during space flight. Fig. 7 shows the general operations sequence of the spacecraft from launch to reentry. Note that the reentry angle is very shallow (1.5 - 2.0 degrees) so that the reentry g forces and heating rates are kept much lower than those which would be expected in a ballistic weapon reentry.

The retropack is jettisoned prior to reentry and the antenna fairing is jettisoned in order to deploy the parachutes. In the re-

entry configuration, the spacecraft weighs about 2650 lbs. and has a ballistic coefficient of about 40 lbs/ft^2. Table I shows the actual reentry weight of each vehicle.

TABLE I

	MA-6 Spacecraft 13	MA-7 Spacecraft 18	MA-8 Spacecraft 16	MA-9 Spacecraft 20
Reentry weight, pounds (approx)	2640	2630	2710	2640
Ballistic Coefficient (W/C_dA) lbs/ft^2	40.6	40.4	41.5	40.6

C_dA is approximately 65 ft^2 for the Mercury spacecraft.

The spacecraft is attached to the booster by means of an adapter ring and two umbilicals. The retropackage is held onto the heat shield by three equally-spaced umbilical straps, making five umbilical conn[illegible]ns in all. These umbilicals and straps are released by explosive disconnects backed up by a mechanical disconnect. Note in Fig. 5 that the location of one of the holddown straps is such that if the strap for any reason "hangs up" on its connector to the spacecraft, it can be seen from the Astronaut's window. This actually occurred on two of the flights and was commented on by the Astronauts (see Sec. IV).

B. Window Properties

A periscope and window are available to the Astronaut for viewing his environment during the flight. In practice, the periscope was not used during reentry and all observations of the reentry phenomena were made through the window. Fig. 9 shows the construction of this window and typical fields of view. The window is made of four panels. The outer two are of Vycor Corning 7900 (essentially, fuzed quartz) and the inner two of tempered glass, Corning 1723. The transmission and polarization characteristics of the window at room temperature are shown in Fig. 10. At high temperatures (see Fig. 11) the transmission in the 2000-6000 Å range shows an increasing absorption at about 2300 Å due to the Si-O band and some small drop in transmission up to 5000 Å.* At 3000°F, the transmittance in the Si-O band drops to 3-5%, while at the 6000 Å region the transmittance is hardly affected at all (i.e., 90-95%). Thus, window heating probably did not significantly affect the transmittance of the Mercury spacecraft window in the visible during reentry. Typical peak temperatures on the aft surfaces of the spacecraft were from 1800 - 2000°F.

*High Temperature Transmission Studies of Window Materials for Project Fire, RAC 499-16, Republic Aviation Corp., 12 Mar 1963 by R. L. Rupp.

The nominal field of view to the rear of the spacecraft is diagrammed in Fig. 12. A one (1) degree depression angle for the eye-view toward the spacecraft roll axis is normally achieved. However, the Astronauts reported that at times they were able to see the axis of the vehicle as near as 20 feet out from the base. This calibration was obtained by observing the end of the deployed drogue chute line which was known to be 20 feet long. The geometry shows that raising the head so that the eye level is one inch higher than the nominal position increases the field of view downwards by another 2-3 degrees. Any angle of attack motion of the spacecraft aids in viewing the area of the near wake phenomena.

C. Materials

The materials used over the major part of the outer surface of the spacecraft (Fig. 6) are outlined in somewhat greater detail below:

1. Heat Shield - Fiberglass - phenolic resin. The temperature response of this material as measured in actual flight is shown in Fig. 13.

2. Window and antenna fairing spacer - Vycor Corning 7900. Composition of Corning 7900:*

SiO_2	96.3%
B_2O_3	2.9%
Al_2O_3	0.4%
Na_2O and K_2O	less than 0.2%

*Engineering Materials Handbook, Mantell, McGraw-Hill, 1958

3. Cone and antenna fairing - René 41, a nickel-based alloy. Composition of René 41:*

Ni	50-58%
Cr	18-20%
Co	10-12%
Mo	9-10.5%
Ti	3-3.3%
Al	1.5-1.8%
Fe	1-2%
C	0.06-0.12%
B	0-.01%

4. Conical section - beryllium shingle sections. These are identified in NASA reports as beryllium shingles but they probably contain small amounts of copper for strength (ref. Astronaut Schirra's comments in his Pilot's Report, Sec. IV C2).

D. Special Conditions

Various special conditions pertain to each of the four orbital Mercury spacecraft flights. These are outlined below and are to be kept in mind when interpreting the data presented in Sections IV and V.

1. MA-6 (3 orbits). John H. Glenn, Astronaut - Pilot.

   a. Launching: First attempt cancelled due to adverse weather on 27 January 1962. Second countdown began 11:30 p.m. est, 19 February 1962. Lift-off occurred at 9:47 a.m. on 20 February 1962.

   b. Reentry: Due to a faulty switch operation indicating that the heat shield might be loose, the retropack was left attached to the spacecraft during reentry and was allowed to ablate off.

*ARDC TR 59-66, "Air Weapons Materials Applications Handbook"

2. MA-7 (3 orbits). M. Scott Carpenter, Astronaut - Pilot.

a. Launching: Countdown started at 11:00 p.m. est, 23 May 1962. Lift-off occurred at 7:45 a.m. est, 24 May 1962.

b. Reentry: Normal

3. MA-8 (6 orbits). Walter M. Schirra, Astronaut - Pilot.

a. Launching: Very smooth countdown with minimum exposure of spacecraft to salt air environment. Lift-off at 7:15 a.m. est, 3 October 1962.

b. Special Materials: Special test materials were located on the conical aft section to determine their resistance to reentry heating effects. A total of eight types of ablation material in nine different configurations were bonded to the exterior surface of nine of the twelve conic section beryllium shingles. No delamination of these samples from the shingles was found upon covery.

c. Reentry: Normal.

4. MA-9 (22 orbits). L. Gordon Cooper, Astronaut - Pilot.

a. Launching: Initial attempt on morning of 14 May 1963 failed due to gantry power generator malfunction. Countdown started again at 12:00 p.m. est, 14 May 1963, with lift-off at 8:04 a.m. est, 15 May 1963.

b. Reentry: Astronaut had to fly spacecraft through reentry manually. Only one of the five umbilical explosive disconnects functioned. Others were mechanically released and squibs remained attached to the spacecraft shoulder during reentry.

IV. DETAILED REENTRY OBSERVATIONS AND DATA

The data pertinent to the near wake obtained during the 18 October 1963 conference with the Astronauts and from the Mercury flight test reports are outlined in this section. For each reentry there is listed the visual reentry events noticed, correlated to time after launch, altitude and velocity. The sources of information are the tape transcripts of the pilots' recorded comments during reentry as published in the Manned Orbital Space Flight reports (Refs. 7-10) and the comments made during the October 1963 conference.

In the tables which follow, the times given in the pilots' recorded comments mark the start of the comment. The Astronaut may not have spoken continuously until the next time mark. The time correlated values of altitude, velocity and acceleration are shown next. Relevant extracts of the pilot's in-flight communication follow. Comments from the conference are given in the last column. Two sketches of the reentry fireball effect made at the conference by the Astronauts are shown in Figs. 17 and 24. Finally, following each table, pertinent excerpts from the Astronaut-Pilots' post-flight report are given (Refs. 7-10).

A. Reentry from First Manned Orbital Space Flight (MA-6)

The first U. S. manned orbital space flight, MA-6, took place on February 20, 1962, at 09:47:39 e. s. t. Lt. Colonel John H. Glenn, Jr. was the Astronaut-Pilot. The flight was for three orbits with recovery in the Atlantic. As noted in the extract from the Pilot's Report,[7] the conditions for this reentry were unusual in that the retropack was left attached over the heat shield.

1. Transcript of events and commentary:[7]

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[7]	Comments from Conference
				(C-communicator) (P-pilot)	
04 41 13				C-Estimating 0.05g at 04 44	
04 41 19				P-Roger	
04 41 21				C-You override 0.05g at that time.	
04 41 29				P-Roger. Friendship Seven.	
04 41 31				P-This is Friendship Seven. I'm on straight manual control at present time. This was, still kicking in and out of orientation mode, mainly in yaw following retrofire, so I am on straight manual now. I'll back it up....	
04 41 43				C-...on reentry	
04 41 44	340,000	24.2			A hissing noise was first heard like fine sand or lightly rubbing fingers on paper. Visor was open during reentry. Started at perhaps 400,000 ft. As reentry progressed, a build-up of color, predominantly orange, was noticed. Pieces came off, from small points to big chunks. The hissing noise seemed to die out.
04 41 45				P-Say again.	
04 41 48				C-Standby.	
04 41 51				P-This is Friendship Seven. Going to fly-by-wire. I'm down to about 15% on manual.	
04 41 58	330,000	24.4		C-Roger. You're going to use fly-by-wire for reentry and we recommend that you do the best you can to keep a zero angle during reentry. Over.	

A

B

-20-

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[7]	Comments from Conference
04 42 07				P-Roger. Friendship Seven.	
04 42 11				P-This is Friendship Seven. I'm on fly-by-wire, back it up with manual. Over.	
04 42 16				C-Roger, understand.	
04 42 27				C-Seven, this is Cape. The weather in the recovery area is excellent, 3-ft waves, only one-tenth cloud coverage, 10 miles visibilit	
04 42 37				P-Roger. Friendship Seven.	
04 42 45				C-Seven, this is Cape. Over	
04 42 47				P-Go ahead, Cape, you're ground, you are going out.	
04 4_ 50			Apparent start of blackout.	C-We recommend that you...	
04 43 14	295,000	24.4		P-This is Friendship Seven. I think the pack just let go.	The color was very bright when pieces let go, the flow funneled back. A fireball formed and seemed to be at a focus for the flow of pieces. It was a solid ball and brighter at the center. Estimated to be 50 ft or so back, about 4 ft diameter with a brighter center perhaps 1 ft in diameter.[28] Fireball rotated with vehicle spin rate. One of the straps holding the retro-pack did not fly off but lay across the window This hung there for some time. It first began to heat at the tip of the free end. The glow or burning then spread all over. Finally the strap broke off and drifted behind, burning, into the wake.
04 43 37	280,000	24.4		P-This is Friendship Seven. A real fireball outside.	
04 44	270,000	24	0.05 g		
04 44 18				P-Hello, Cape. Friendship Seven. Over.	
04 45 16				P-Hello, Cape. Friendship Seven. Over.	
04 45 41				P-Hello, Cape. Friendship Seven. Do you receive? Over.	
04 46 17	200,000	19.0		P-Hello, Cape. Friendship Seven. Do you receive? Over.	
04 47 12	130,000	9.0	peak g		
04 47 15				C-...How do you read? Over.	
04 47 16				P-Loud and clear; how me?	
04 47 19				C-Roger, reading you loud and clear. How are you doing?	
04 47 22				P-Oh, pretty good.	
04 47 26				C-Roger. Your impact point is within 1 mile of the up-range destroyer.	

Pilot's Recorded Comments[7]
Roger. Friendship Seven.
This is Friendship Seven. I'm on fly-by-wire, back it up with manual. Over.
Roger, understand.
Seven, this is Cape. The weather in the recovery area is excellent, 3-ft waves, only one-tenth cloud coverage, 10 miles visibility.
Roger. Friendship Seven.
Seven, this is Cape. Over
Go ahead, Cape, you're ground, you are going out.
We recommend that you...
This is Friendship Seven. I think the pack just let go.
This is Friendship Seven. A real fireball outside.
Hello, Cape. Friendship Seven. Over.
Hello, Cape. Friendship Seven. Over.
Hello, Cape. Friendship Seven. Do you receive? Over.
Hello, Cape. Friendship Seven. Do you receive? Over.
...How do you read? Over.
Loud and clear; how me?
Roger, reading you loud and clear. How are you doing?
Oh, pretty good.
Roger. Your impact point is within 1 mile of the up-range destroyer.

A

B

1-

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[7]	Comments from Conference
04 47 30				P-Roger.	
04 47 31				C-. . . Over.	The fireball appeared like a long bright cylinder, the near end of which looked like a ball. There was no jitter or rapid motion of the ball but it would move corresponding to vehicle attitude and roll. As it faded, the center faded first. It was essentially gone by peak g time.
04 47 32				P-Roger.	
04 47 40				C-This is Cape, estimating 04 50. Over.	
04 47 44				P-Roger, 04 50.	
04 47 49	90,000	2.6		P-Okay, we're through the peak g now.	
04 47 51				C-Seven, this is Cape. What's your general condition? Are you feeling pretty well?	
04 47 55				P-My condition is good, but that was a real fireball, boy.	
04 48 01				P-I had great chunks of that retropack breaking off all the way through.	
04 48 04				C-Very good; it did break off, is that correct?	
04 48 07				P-Roger. Altimeter off the peg indicating 80,000.	
04 48 11				C-Roger, reading you loud and clear.	
04 48 13				P-Roger.	
04 48 19				C-Seven, this is Cape. You're . . . will be within 1 mile of the uprange destroyer. Recovery weather is very good. Over.	
04 48 26				P-Roger, understand. 55,000, standby, MARK.	
04 48 37				P-I'm getting all kinds of contrails and stuff outside out here	Glenn notes that these condensation trails were similar to those created by aircraft at high altitude.
04 48 42				C-Roger. Say again your altitude, please. You were broken up.	
04 48 45	45,000			P-45,000.	

Pilot's Recorded Comments[7]
oger.
. Over.
oger.
his is Cape. estimating
4 50. Over.
oger, 04 50.
kay, we're through the
eak g now.
even, this is Cape. What's
our general condition?
re you feeling pretty well?
y condition is good, but
at was a real fireball, boy.
had great chunks of that
etropack breaking off all
e way through.
ery good; it did break off,
that correct?
oger. Altimeter off the
eg indicating 80,000.
oger, reading you loud
nd clear.
oger.
even, this is Cape. You're
. will be within 1 mile of
e uprange destroyer. Re-
very weather is very good.
ver.
oger, understand. 55,000,
andby, MARK.
n getting all kinds of con-
ails and stuff outside out
re.
oger. Say again your
titude, please. You were
oken up.
,000.

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2. Extract from Pilot's Report.[7]

"After having turned around on the last orbit to see the particles, I maneuvered into the correct attitude for firing the retrorockets and stowed the equipment in the ditty bag....I received a countdown from the ground and the retrorockets were fired on schedule just off the California coast.

"I could hear each rocket fire and could feel the surge as the rockets slowed the spacecraft. Coming out of zero-g condition, the retrorocket firing produced the sensation that I was accelerating back toward Hawaii. This sensation, of course, was an illusion.

"Following retrofire the decision was made to have me reenter with the retropackage still on because of the uncertainty as to whether the landing bag had been extended. This decision required me to perform manually a number of the operations which are normally automatically programed during the reentry. These maneuvers I accomplished. I brought the spacecraft to the proper attitude for reentry under manual control. The periscope was retracted by pumping the manual retraction lever.

"As deceleration began to increase I could hear a hissing noise that sounded like small particles brushing against the spacecraft.

"Due to ionization around the spacecraft, communications were lost. This had occurred on earlier missions and was experienced now on the predicted schedule. As the heat pulse started there was a noise and a bump on the spacecraft. I saw one of the straps that holds the retrorocket package swing in front of the window.

"The heat pulse increased until I could see a glowing orange color through the window. Flaming pieces were breaking off and flying past the spacecraft window. At the time, these observations were of some concern to me because I was not sure what they were. I had assumed that the retropack had been jettisoned when I saw the strap in front of the window. I thought these flaming pieces might be parts of the heat shield breaking off. We know now, of course, that the pieces were from the retropack.

"There was no doubt when the heat pulse occurred during reentry but it takes time for the heat to soak into the spacecraft and heat the air. I did not feel particularly hot until we were getting down to about 75,000 to 80,000 feet. From there on down I was uncomfortably warm, and by the time the main parachute was out I was perspiring profusely.

"The reentry deceleration of 7.7 g was as expected and was similar to that experienced in centrifuge runs. There had been some question as to whether our ability to tolerate acceleration might be worse because of the 4-1/2 hours of weightlessness, but I could note no difference between my feeling of deceleration on this flight and my training sessions in the centrifuge.

"After peak deceleration, the amplitude of the spacecraft oscillations began to build. I kept them under control on the manual and fly-by-wire systems until I ran out of manual fuel. After that point, I was unknowingly left with only the fly-by-wire system and the oscillations increased; so I switched to auxiliary damping, which controlled the spacecraft until the automatic fuel was also expended. I was reaching for the switch to deploy the drogue parachute early in order to reduce these reentry oscillations, when it was deployed automatically. The drogue parachute stabilized the spacecraft rapidly."

B. Reentry of Second Manned Orbital Space Flight (MA-7)

The second manned orbital flight, MA-7, was conducted on May 24, 1962, with lau·ay 24, 1962, with launch at 07:45:16 a.m., e.s.t. Lt. Commander M. Scott Carpenter was the Astronaut-Pilot. The flight was for three e flight was for three orbits with recovery in the Atlantic.

1. Transcript of events and commentary:[8]

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[8]	Comments from Conference
04 43 40	317,000	24.4	Last communication from range station (apparent blackout after this).	C-Aurora Seven, Cap Com. Do you still read?	First heard hissing, like steam or fingers lightly rubbing over paper. The first thought was that the heat shield was outgassing. Must have started above 400,000 ft.
04 43 42.5				P-Roger. Loud and clear.	
04 43 52				P-I don't have a roll rate in yet. I'll put some in when I begin to get the g buildup.	
04 44 07.5	305,000	24.4	Pilot gets 0.05 g light.	P-I only was reading 0.5 g's on the accelerometer. Okay, here come some rates.	An initial increase in the "haze level" was seen before the general fireball phenomena.
04 44 28.5	295,000	24.4	Indicated 0.05 g on published trajectory.	P-I've got the orange glow. I assume we're in blackout now. Gus, give me a try. There goes something tearing away.	A suggestion of orange in this whitish glow. Note Fig. 17, the pilot's sketch of the fireball effect. A yellow doughnut was seen. The background inside and outside the doughnut looked about the same. A steady wake with no motion other than that corresponding to vehicle attitude. Tracers converged through the doughnut. It appeared as though one were looking back into a pipe of hot, orange, radiating gas. A "necking down" motion was noted. The doughnut was perhaps 150 ft back assuming a 6 or 7 ft diameter hole in the doughnut. The glow decreased as peak g approached. The smoke streamed back in grey wisps into the doughnut and hole.
04 44 52.5				P-Okay. I'm setting in a roll rate at this time.	
04 45 06				P-Going to Aux Damp.	
04 45 13.5	275,000	24.4		P-I hope we have enough fuel. I get the orange glow at this time.	
04 45 30.5				P-Bright orange glow.	
04 45 43.5				P-Picking up just a little acceleration now.	
04 46 17.5	242,000	23.6		P-Not much glow; just a little. Reading 0.5 g. Aux Damp seems to be doing well. My fuel, I hope, holds out. There is 1 g. Getting a few streamers of smoke out behind. There's some green flashes out there.	

'a Seven, Cap Com. u still read? . Loud and clear. t have a roll rate in I'll put some in when n to get the g buildup. was reading 0.5 g's accelerometer. here come some rates. ot the orange glow. me we're in black- w. Gus, give me a There goes some- tearing away. I'm setting in a roll t this time. to Aux Damp. we have enough fuel. he orange glow at me. orange glow. g up just a little ration now. uch glow; just a Reading 0.5 g. amp seems to be well. My fuel, I hope, out. There is 1 g. a few streamers of out behind. There's green flashes out there.

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Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[8]	Pilot's Recorded Comments[8]	Comments from Conference
04 47 02.5				P-Reentry is going pretty well. Aux Damp seems to be keeping oscillations pretty good. We're at 1-1/2 g's now. There was a large flaming piece coming off. Almost looked like it came off the tower.	P-Reentry is going pretty well. Aux Damp seems to be keeping oscillations pretty good. We're at 1-1/2 g's now. There was a large flaming piece coming off. Almost looked like it came off the tower.	The green flashes seemed to rise vertically in front of the window (see Fig. 17) and were not the same configuration as the fireball. The flashes seemed to come from the cylindrical section of the spacecraft (the "tower") and was brighter than the orange glow about the window.
04 47 36.5				P-Oh, I hope not.	P-Oh, I hope not.	
04 47 47	190,000	18.6		P-Okay. We're reading 3 g's, think we'll have to let the reentry damping go this time. Reading now 4 g's. The reentry seems to be going okay. The rate's there that Aux Damp appears to be handling. I don't think I'm oscillating too much; seem to be rolling right around that glow--the sky behind. Auto fuel still reads 14 (percent) at 6.5 g's. Rates are holding to within 1-1/2 degrees per second indicating about 10 degrees per second roll rate. Still peaked at 6.8 g's. The orange glow has disappeared now. We're off peak g. Still indicating 14 (percent) auto fuel; back to 5 g's.	P-Okay. We're reading 3 g's, think we'll have to let the reentry damping go this time. Reading now 4 g's. The reentry seems to be going okay. The rate's there that Aux Damp appears to be handling. I don't think I'm oscillating too much; seem to be rolling right around that glow--the sky behind. Auto fuel still reads 14 (percent) at 6.5 g's. Rates are holding to within 1-1/2 degrees per second indicating about 10 degrees per second roll rate. Still peaked at 6.8 g's. The orange glow has disappeared now. We're off peak g. Still indicating 14 (percent) auto fuel; back to 5 g's.	One such piece, recognized as a strap, "floated" in back of the capsule for a few seconds (see Fig. 17), then was picked up by the wake. Many particles and parts seemed to move back with surprisingly low velocities. The parts all glowed. The glow disappeared after peak g's. In general, it was not as bright as was expected after John Glenn's report.
04 49 18.5	90,000	2.6		P-And I'm standing by for altimeter off the peg. Cape, do you read yet? Altimeter is off the peg. 100 (1,000) ft rate of descent is coming do[wn,] cabin pressure is--cabin	P-And I'm standing by for altimeter off the peg. Cape, do you read yet? Altimeter is off the peg. 100 (1,000) ft., rate of descent is coming down, cabin pressure is--cabin	

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Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[8]	Pilot's Recorded Comments[8]	Comments from Conference
				pressure is holding okay. Still losing a few streamin No, that's shock waves. Smoke pouring out behind. Getting ready for the drog at 45 (1,000 ft).	essure is holding okay. ll losing a few streaming. , that's shock waves. ioke pouring out behind. tting ready for the drogue 45 (1,000 ft).	
04 49 58				P-Oscillations are pretty goo I think ASCS has given up ghost at this point. Emer gency drogue fuse switch i on.	cillations are pretty good. think ASCS has given up the ost at this point. Emer- ncy drogue fuse switch is .	
04 50 20.5	40,000	0.6	Garbled communication.	C-... ?	. ?	On final descent, spacecraft went through some clouds and noticed an effect similar to the reentry flow of gases into the "fireball" behind the vehicle.

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2. Extract from Pilot's Report.[8]

"Retropack jettison and the retraction of the periscope occurred on time. At this time, I noticed my appalling fuel state and realized that I had controlled retrofire on both the manual and fly-by-wire systems. I tried both the manual and the rate-command control modes and got no response. The fuel gage was reading about 6 percent, but the fuel tank was empty. This left me with 15 percent on the automatic system to last out the 10 minutes to 0.05 g and to control the reentry. I used it sparingly, trying to keep the horizon in the window so that I would have a correct attitude reference. I stayed on fly-by-wire until 0.05 g. At 0.05 g I think I still had a reading of about 15 percent on the automatic fuel gage. I used the window for attitude reference during reentry because of the difficulty I had experienced with the attitude displays prior to retrofire.

"I began to hear the hissing outside the spacecraft that John Glenn had described. The spacecraft was alined within 3° or 4° in pitch and yaw at the start of the reentry period. I feel that it would have reentered properly without any attitude control. The gradual increase of aerodynamic forces during the reentry appeared to be sufficient to aline the spacecraft properly. Very shortly after 0.05 g, I began to pick up oscillations on the pitch and yaw rate needles. These oscillations seemed about the same as those experienced in some of the trainer runs. From this I decided that the spacecraft was in a good reentry attitude, and I selected the auxiliary damping control mode.

"I watched both the rate indicator and the window during this period, because I was beginning to see the reentry glow. I could see a few flaming pieces falling off the spacecraft. I also saw a long rectangular strap going off in the distance. The window did not light up to the extent that John Glenn reported. I did not see a fiery glow prior to peak acceleration.

"I noted one unexpected thing during the heat pulse. I was looking for the orange glow and noticed instead a light green glow that seemed to be coming from the cylindrical section of the spacecraft. It made me feel that the trim angle was not right and that some of the surface of the recovery compartment might be overheating.

However, the fact that the rates were oscillating evenly strengthened my conviction that the spacecraft was at a good trim angle. The green glow was brighter than the orange glow around the window.

"At peak acceleration, oscillations in rate were nearly imperceptible, since the auxiliary damping was doing very well. The period of peak acceleration was much longer than I had expected. I noticed that I had to breathe a little more forcefully in order to say normal sentences."

C. Reentry from Third Manned Orbital Space Flight (MA-8)

The third manned orbital flight, MA-8, was conducted on 30 October 1962 with launch at 7:15 a.m., e.s.t. Lt. Commander Walter M. Schirra, Jr. was the Astronaut-Pilot. The flight was for six orbits with recovery in the Pacific. It should be noted that the flight of MA-8 went with particular smoothness. In the words of the Astronaut - it was a textbook flight. Thus, the spacecraft had very little exposure to salt air prior to launch and the Astronaut-Pilot had more time and attention to devote to observations during reentry.

1. Transcript of events and commentary:[9]

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[9]	Comments from Conference
09 00 40				C-Wally, by the way, how do you feel? All your systems okay at this time?	
09 00 43	315,000	24.4	Last message before blackout.	P-Oh, they're beautiful--very good. Every control mode has worked perfectly.	
09 00 53	310,000	24.4	Ground reports telemetry loss.	C-Lost you on T/M.	Did not hear the hissing sound.
09 01 19	295,000	24.4		P-I have selected aux damp and rate command at this. The window is almost completely occluded. It would be impossible to see out of it at this point.	This occlusion was doubtless due to an oblique from the sun scattering from the window surface. Such scattering was also noted during orbital flight.
09 01 38	285,000	24.4	0.05 g	P-I'm seeing things come off, but I can't see them very clearly. There we go into 0.05, a green. I am hands off at this point. In rate command, in aux damp. And I have a roll rate started. A slight pitch rate, not bad at all. I can see out the window for some strange reason at last. There goes another spiral like looking device. I will give another blood pressure at this point,	Parts first seemed to go straight back and later to exhibit a sort of "necking down" path. The long spiral looking device was a retro hold-down strap. This sat in the stagnation region for a second or so, 10 or 15 feet out from the window; it was hot with whitish particles spreading out.

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Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[9]	Comments from Conference
				subsequent to 0.05 g. All rates are very nominal. Rate command is working quite well I would say.	
09 02 44	243,000	23.9		P-Going back into g-field. And the attitude looks very stable. I'm rolling right around the horizon. I'm going to stop my blood pressure at this time--and sit back here and regroup. I can see the ion layer. I'm inverted at this time.	The ion layer referred to was a hazy whitish glow. Thought that it might be a bow shock effect.
09 03 14	225,000	23.3		P-Attitudes are controlling very well. Seems to be plenty of manual fuel. I'm still at 72 percent. Definitely has a cyclic rate in pitch at this point. Yaw is fairly stiff; g is building up. Capsule is quite stable. There is a green flow--and looks like orange streaks every once in a while. RSCS is doing very well on reentry. Rather unusual slow roll. Building up to 2 g's. I have plenty of fuel in rate command. Seeing sparkles coming by now. A definite green glow, like a limeade; g's building up. Oscillations are very good at this point. About 3 g.	The green flow appeared as though one were looking up a Bunsen burner flame, about 10-20 feet long. The green glow was like a doughnut--you could see through the center (see Fig. 17).
09 04 18	177,000	18.8		P-Still in a relatively horizontal attitude. Rate command working well. Glad she's holding. Doing very well. Coming up to 5-1/2(g). Rate command still holding,	Most of the color was gone when 5 g was reached.

t's Recorded omments[9]
quent to 0.05 g. All are very nominal. :ommand is working well I would say. back into g-field. ie attitude looks very . I'm rolling right d the horizon. I'm to stop my blood ure at this time--and :k here and regroup. see the ion layer. verted at this time. ies are controlling vell. Seems to be of manual fuel. I'm t 72 percent. Definitely has a cyclic rate in it this point. Yaw ly stiff; g is building apsule is quite . There is a green and looks like orange s every once in a RSCS is doing vell on reentry. unusual slow roll. ng up to 2 g's. I lenty of fuel in rate and. Seeing sparkles g by now. A definite glow, like a limeade; ilding up. Oscilla- re very good at this About 3 g. a relatively hori- attitude. Rate com- working well. Glad holding. Doing very Coming up to 5-1/2(g). ommand still holding,

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Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[9]	ilot's Recorded Comments[9]	Comments from Conference
				fuel is still 70 (percent), seems low. Coming up to 6-1/2(g), 7 g's. Coming up to 8g. Rate command holding. Taking a pretty big yaw out. Not too bad. I have it pretty well. Manual (fuel) is 60 percent. She's flying it very well.	is still 70 (percent), ms low. Coming up to /2(g), 7 g's. Coming up g. Rate command ling. Taking a pretty yaw out. Not too bad. ve it pretty well. ual (fuel) is 60 per- t. She's flying it very l.	
09 05 29	100,000	3.5		P-Coming off. Peak-g was an indicated 7-1/2(g).	ning off. Peak-g was ndicated 7-1/2(g).	
09 05 38	93,000	2.7	Apparent end of blackout.	C-I read you weak. How do you read?	ad you weak. How do read?	
09 05 40				P-Roger. Read you well, loud and clear. I still have about 3 g on. Capsule performing very well. Rate command holding pretty well. Altimeter off the peg. Attitudes holding very well.	er. Read you well, l and clear. I still have ut 3 g on. Capsule per- ning very well. Rate mand holding pretty l. Altimeter off the Attitudes holding well.	
						After landing, it was noted that the window was covered by a clear bubbly deposit. This rubbed off in the water when one of the swimmers brushed against the window.

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2. Extract from Pilot's Report. [9]

"The beginning of the actual entry into the sensible atmosphere, with the attendant cues, was a very thrilling experience. Because my vision was somewhat obscured by perspiration on the inside surface of the visor, the cue for occurrence of the important event, 0.05 g, was my visual sensing of the roll rate that was automatically induced by the control system rather than by the 0.05 g event light on the panel. The spacecraft with a roll rate is something you just cannot effectively visualize in your mind. It is a very nice series of slow rolls, and you really feel as if you are back in the old fighter seat, just playing games. Looking out at the sky and at the surface of the earth which was starting to brighten up, I observed that the roll pattern was very slow and deliberate. You could integrate your attitude out of this very easily, and I knew that the spacecraft was as stable as an airplane.

"As the acceleration buildup began, I could see external cues which were of great interest. I missed the hissing that John Glenn and Scott Carpenter described, possibly because I was concentrating so much on how the RSCS system was performing....

"I did see the green glow from the cylindrical section. It was a very pretty color, probably best described as a shade similar to limeade (a little green and chartreuse mixed together). This shade included a slightly stronger yellow cast than I had anticipated from earlier descriptions. One opinion which was ventured that might explain the green-yellow color is the copper treatment on the beryllium shingles. In fact, burning copper in a Bunsen burner flame is a good approximation to the effect that I saw. I did not see any distinctive color differences resulting from the different ablation panels that had been bonded to the beryllium shingles. There were no variances in color, such as a chromatic or a rainbow effect.

"The altimeter came off the peg very nicely. I manually deployed the drogue parachute at 40,000 feet. There was a definite strong thrumming accompanied by the drogue deployment, somewhat like being on a bumpy road.... The window definitely was further occluded during reentry."

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D. Reentry from Fourth Manned Orbital Space Flight (MA-9)

The fourth manned orbital space flight, MA-9, was launched at 8:04:13 a.m., e. 8:04:13 a.m., e.s.t. on May 15, 1963. Capt. L. Gordon Cooper, Jr. was the Astronaut-Pilot. The flight lasted for 22 orbit sted for 22 orbits with recovery in the Pacific. Due to the complete failure of automatic reentry modes, the Astronaut had to fly the ut had to fly the spacecraft manually and therefore had little time to record reentry phenomena verbally during the reentry process. reentry process. He nevertheless obtained a clear picture of the event as revealed in his sketch, shown in Fig. 24, of the reentry 4, of the reentry phenomena and the conference comments.

1. Transcript of events and commentary:[10]

Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[10]	s Recorded mments[10]	Comments from Conference
34 02 49				C-It's been a real fine fligh Gordo. Real beautiful al way. Have a cool reentr will you?	a real fine flight, Real beautiful all the ve a cool reentry,	
34 02 55				P-Roger, John. Thank you	ohn. Thank you.	
34 03 24				C-Faith Seven, CSQ.	en, CSQ.	
34 03 27				P-Roger, CSQ.	SQ.	
34 03 28				C-ASCS 0.05 g switch fuse the off position Over.	5 g switch fuse to sition Over.	
34 03 33				P-Roger. 0.05 g switch fu the off position.	).05 g switch fuse to sition.	
34 03 37				C-Roger.		
34 08 ?				P-Roger.		Did not notice the hissing noise, had his visor closed.
34 08 21				C-Faith Seven, Faith Seven, Faith Seven, this is RTK. M and O (Maintenance an Operations). How copy?	en, Faith Seven, en, this is RTK, (Maintenance and s). How copy?	The umbilical squibs did not blow off on this vehicle and they all hung on during reentry.
34 08 27				P-Roger, Faith Seven. Reading you loud and clea	aith Seven. ou loud and clear.	
34 08 30				C-Roger, RTK here. I hav landing area weather for you. Ready to copy?	TK here. I have rea weather for dy to copy?	

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Time	Altitude ft	Velocity kft/sec	Event	Pilot's Recorded Comments[10]	's Recorded mments[10]	Comments from Conference
34 06 34				P-Roger.		First noted a faint shiny glow of orangy color - no objects in view (i.e., parts). Then got the appearance of a wake with converging flow.
34 09 19			0.05 g			The color intensity increased and the fireball formed (see Fig. 24). Seemed to be a uniform steady ball, moving with attitude of the vehicle. The color of the fireball was the same as the surrounding flow--only more intense. A "necking down" of the flow noted. A retropack strap hung across the window for a while - waving. The loose end got hot first, glowing orange, then white. Glowing crept up to hinge and strap finally broke loose, burning, floated in view for a few seconds and then picked up speed as it was taken through the neck by the flow.
						The fireball died away by peak g. Generally, one was able to "feel" the heat from the event. The slow relative velocity of the parts and straps was surprising.

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2. Extract from the Pilot's Report.[10]

"After retrofire, there is a period of several minutes prior to the start of reentry (0.05 g). As you approach 0.05 g, the spacecraft control becomes sluggish and feels as though it wants to start reentry.

"As in the retrofire case, all of us knew that we could reenter on manual control. However, the flight plans generally called for autopilot control during reentry. Nevertheless anomalies of system function resulted in partial manual control in all but Wally's flight. I used manual proportional control on MA-9 since I had lost the ASCS and standby inverters during the 20th orbital pass. The reentry worked out very successfully and showed again that the pilot can accomplish this control task very adequately.

"I found that the oscillations of the spacecraft were not difficult to damp until I descended to an altitude of approximately 95,000 feet. At this point, the amplitude of spacecraft motions increased as they normally do and it took a substantial increase of control inputs to keep within comfortable limits. The oscillation became more severe at approximately 50,000 feet, but I deployed the drogue parachute at 42,000 feet, as planned, and the spacecraft was quickly stabilized.

"The g-forces are more sustained on reentry than on launch but are still easily tolerable.

"During reentry there was no uncomfortable increase in cabin temperature. If the pilot is performing a manual reentry, he will be perspiring profusely when landing, but mostly because of the work load rather than the increased temperature."

V. CONCLUSIONS AND DISCUSSION

The visual effects of atmospheric reentry were first noticed by the Mercury Astronauts at a very high altitude (above 300 kft). These luminous effects along the trajectory were very striking to the eye. The vividness of the phenomena was somewhat unexpected. On the fourth and final Mercury flight, the Mercury Astronauts felt that it might be of interest to photograph the wake "fireball" as it formed and progressed, so a movie camera was mounted in the capsule for use by Astronaut Cooper. The camera was such that the pilot would have to hold it manually up to the window in order to take pictures. Unfortunately, required tasks during reentry made it impossible for Astronaut Cooper to do so.

In spite of the tenseness of the situation during reentry, the Astronauts were able to make key observations of and detailed comments on wake formation and behavior. These results are largely in accord with aerodynamicists' present understanding of the general wake flow field pattern (Refs. 1-6). The authors draw the following conclusions from the observations of the near wake and base flow reentry phenomena by the Mercury Astronauts:

1. The description of the general pattern of the flow field seems to be similar to that which would be expected from the patterns shown in pictures of high-speed projectiles fired in ballistic ranges (Refs. 1-6). The detailed observations combine to give a description of a "well behaved" closure region forming a high temperature wake neck a few body diameters behind the vehicle. In general, the neck region - "a funnelling effect" - was clearly defined and much brighter than the rest of the base flow as seen through the spacecraft window.

2. One of the first reentry effects was a pronounced "hissing" noise noticed by Astronauts Glenn and Carpenter. The noise started at altitudes of over 400,000 feet, sounded like someone rubbing on sandpaper or like steam escaping and decreased as the reentry progressed. Astronauts Schirra and Cooper did not notice this noise. The extent of the noise level is difficult to determine but can be judged somewhat by comparison with launch noise. The measured launch noise level is 160 db outside the capsule and 120 db inside; with the flight helmet on and the visor down, the noise is cut down another 20-30 db. Thus, the hissing noise is likely to be of the order of 80-90 db outside the capsule. No reasonable phenomenon has been suggested with a noise effect of this level at such a high altitude.

Another possibility, of course, is that the noise did not originate from without the capsule but was an auditory hallucination very much the same as the "ringing" in the ear often observed. The etiology of this phenomenon is not at all well understood but certain conjectures may be made.

The atmosphere in the Mercury capsule was pure oxygen at roughly 1/3 atmospheric pressure (5 psi). The absence of nitrogen which has a different solubility than oxygen in the blood is known to have a profound physiological effect. The absence of nitrogen over an extended period of time causes the inner ear as well as the mastoid bone to become de-nitrogenated, its place being taken by oxygen. It is conjectured that this leads to a modification of the ear function. This modification may cause either over-stimulation or lack of damping in the cochlea. It is interesting to note, and rather in contradiction of this hypothesis, that Astronaut Cooper who spent the longest time in the capsule did not notice this noise. Colonel Glenn whose space flight was the shortest did indeed notice it. We did not have the records of their behavior during their training at our disposal and thus do not know whether there are any individual differences in the astronauts' response to prolonged weightlessness as well as their reaction to a pure oxygen atmosphere.*

*The authors gladly acknowledge the clarifying discussions on this matter with Dr. Herbert Pollack, M. D., of IDA.

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3. The first appearance of radiation at altitudes like 350,000 feet was a faint grey-whitish yellow haze giving the Astronauts an impression of "hot" air. This suggests that the bow shock was just forming and that the inviscid flow was the principal radiator. This altitude for formation of the bow shock is reasonable from theoretical considerations.* (Strong color effects came on somewhat later in the trajectory.)

4. The convergence of the flow field into the wake neck produced a "fireball" that was about 1/2 the size of the base diameter and about three body diameters behind the spacecraft. A reasonable consistency is shown in the apparent size of the "fireball" observed by the Astronauts when their sketches and verbal descriptions of its appearance are combined (Figs. 17 and 24). The lateral field of view through the window at the position at which the fireball is pictured in the sketches is about 25°. The angular subtent of the fireball obtained from these two sketches is 6.3° from Fig. 17 and 6.1° from Fig. 24. The statements of the Astronauts as to their impressions of the size and location of the fireball are tabulated in Table II following.

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*Probstein, R., "Shock Wave and Flow Field Development in Hypersonic Reentry," ARS Journal, 31, 185-193 (1961).

TABLE II

	Fireball Shape	Distance (feet)	Fireball Outer Dia. (feet)	Calculated Fireball Outside dia. Angular subtent
Conference Descriptions:				
Glenn (MA-6)	Ball	50	4	4.8°
Carpenter (MA-7)	Doughnut	*150	14	5.5°
Schirra (MA-8	Doughnut	25	3-1/2	8°
Cooper (MA-9)	Ball	25	3-1/2	8°
Angular subtent average				6.6°
Conference Sketches:				
Carpenter and Schirra				6.3°
Cooper				6.1°
Overall average				6.5°

*NOTE: Astronaut Carpenter said that the "doughnut" shaped fireball appeared as though it were about 150 ft. behind the vehicle assuming the hole in the "doughnut" were 6-7 ft. in diameter. Approximate scaling from his sketch would give a corresponding outside diameter of about 14 feet. These dimensions are proportionally correct for a doughnut in the neck region. Carpenter suggested that the distance might have been closer than 150 feet.

The Mercury Astronauts were able to view the "fireball" more or less continuously during those times when they looked at the flow field through the window. Thus, the effect must have been located

at least 20 feet to the rear of the vehicle; otherwise, intermittently, it would have been out of the field of view. (See Field of View Diagram, Fig. 12.) If the diameter of the luminous wake neck is like one-half the spacecraft diameter, the average angular subtent of 6.5° would place the start of the luminous neck at about 30 feet behind the Astronaut's eye location, or about 23 feet behind the base of the spacecraft (the top of the antenna fairing). Thus, there is strong evidence from the Astronauts' sketches that the region of maximum luminosity occurs in the region where the recompression zone is expected to be located.

5. The "fireball" position seemed to vary only with the vehicle motion and angle of attack. The wake neck (the fireball) was described to be very steady to the eye and to have a motion that closely followed the vehicle as the angle of attack varied. The spacecraft rolled about the centerline axis as well as oscillated with angle of attack. It should be remembered that the eye can discern fluctuations only up to about 50 cycles per second. Hence, fluctuations of much higher frequencies could have been present but not observed.

6. The region of maximum luminosity was described in two cases as having a ball shape and in two cases a doughnut shape. The doughnut-shaped "fireball" was observed by Astronauts Carpenter and

Schirra while Astronauts Glenn and Cooper saw a ball (Figs. 17 and 24). From the descriptions it is not possible to determine whether or not the inner core was hotter or colder than the surrounding inviscid flow. The difference in colors may be related to the degree of salt spray exposure prior to launch and also to the protective materials used on the surface of the spacecrafts. It is also important to note that both Glenn and Cooper had an abnormal reentry situation due to the attached retropack (Glenn) and unfired umbilical squibs (Cooper). Astronaut Glenn's capsule was also held at the launch site for about six months and apparently there was considerable opportunity for a salt spray coating to accumulate, although the capsule was mostly enclosed in a protective enclosure. In his flight he saw an orange ball which would be consistent with the sodium and a brilliant display no doubt associated with the disintegrating retropack. Schirra, who had short capsule storage and countdown periods, saw the neck as doughnut shape with green color. The green probably came from the copper in the heat shield material on the aft portion of the capsule. It is interesting to note that Astronaut Glenn remarked on seeing the center of the fireball fade away first as reentry was completed. They all had the impression of sitting inside a bunsen burner and looking up into the flame. In the description of whether a doughnut or ball was

seen, it should be remembered that each man was observing over different parts of the reentry, with only some overlap (see Section IV). The present understanding of the flow field allows for both ball and doughnut-shaped temperature and/or luminosity recompression regions, depending on the reentry conditions (Refs. 1-6).

It appears from their sketches (Figs. 17 and 24) and descriptions that each Astronaut was referring to the viscous portion of the flow field when using terms such as a "doughnut" or a "fireball" for the shape of the recompression region. From the size of these regions of high luminosity - say 1/2 a body diameter - it is likely that they did not include a large part of the inviscid flow.

We would also like to offer here an alternate tentative explanation for the difference in the shapes of the luminous zone as reported by the Astronauts. If a person is shown a disc of uniform color but non-uniform illumination, then the eye will tend to make some subjective adjustments. If the center of the disc, say, is of higher intensity than the edges, then the tendency would be to shift the color either toward the green or away from the green. The reason for this is that the eye is trying to compensate for its increased sensitivity in the 5500 Å region (green). Thus, a doughnut-like shape may appear where there is none just because the center of the disc

is either at a higher or lower intensity. The ability of individuals to distinguish small changes in hue (j.n.d.) varies considerably. We were not able to ascertain whether there were any such differences among the four Astronauts whom we interviewed.

7. The heat transfer in the separated flow region just behind the heat shield shoulder was not severe. Umbilical launch separation squibs attached at the capsule shoulder on Astronaut Cooper's vehicle (MA-9) (which did not operate due to faulty charge packaging) were found to be only slightly burned upon recovery. In addition, the retrorocket holddown straps did not burn at the vehicle junction point. These metal straps (see Figs. 5 and 17) were about 24 inches by 1 inch in size. They disconnected at the retrorocket junction and were then free to flap back around the shoulder of the vehicle. One strap was such that the loose end swung across the window. The Astronauts saw from the coloration of the strap that it began heating at the far loose end. The heat moved up the strap to the junction point where the temperature increased until burnoff.

8. The relative velocity in the recirculating base region (Fig. 2a) of the vehicle is probably very low and stable. The retropack holddown straps described above eventually burned off from the vehicle and drifted back into the base region. Each of the Astronauts

described this as an unusual sight in that the straps seemed to be trapped in the base region, following along with the vehicle. The relative position of a strap floating in the base region is noted in Fig. 17 as sketched by Astronaut Carpenter. Each Astronaut saw the straps gradually begin to move away and then suddenly be caught by the high velocity and whipped downstream with a "funneling" motion through the "neck". Other particles of significant size ablating from the vehicle had the same behavior. The small deceleration of the strap may be due to the small absolute value of free stream dynamic pressure rather than specifically to a relatively small base region dynamic pressure.

9. The metal straps described above continued to heat up as they drifted through the base region. The Astronauts made the observation that as the straps were suspended in the base flow region they appeared to continue heating, indicating that significant temperatures exist in this region.

In line with the NASA program to solicit experiments from the scientific community for future manned reentry capsule flights, the authors conclude with the following suggestions for some simple experiments which would provide additional very useful information about properties in the wake region:

1. A high speed movie camera could be mounted in the capsule which would record the wake formation and behavior during reentry. The ability to recover the instrument is a valuable asset. Current ballistic missile instrumentation programs generally require that information gathered has to be telemetered to the ground. The plan to use a camera during Astronaut Cooper's flight is certainly to be commended. The camera should be mounted and rigged for automatic operation, however.

2. The inclusion of a wide field cine-spectrograph with about a 5 Å or better resolution would be a second step in obtaining wake properties. This would result in helping to define what species (from air and ablation materials) radiated in the neck region and the altitude at which air and contaminant radiation began.

3. It was very useful to have a technically competent observer describe the near wake reentry events in great detail. In view of the important needs of the nation with respect to the wake problem, it may be useful to brief future Astronaut-Pilots on expected near and far wake visual phenomena and on the specific questions currently of interest to the reentry physicists concerned with wake properties.

FIGURE 1

FLOW FIELD AROUND MERCURY SPACECRAFT

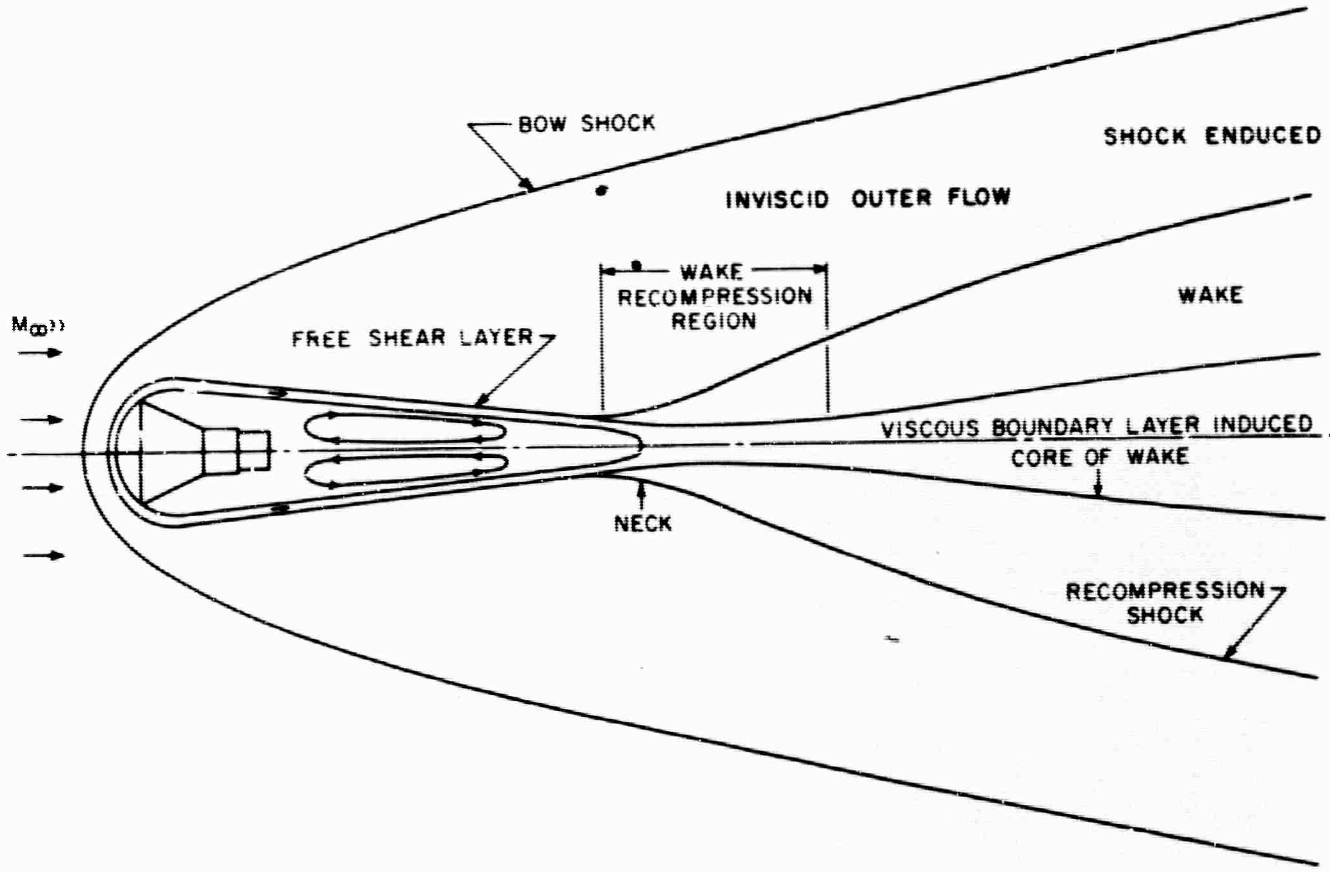
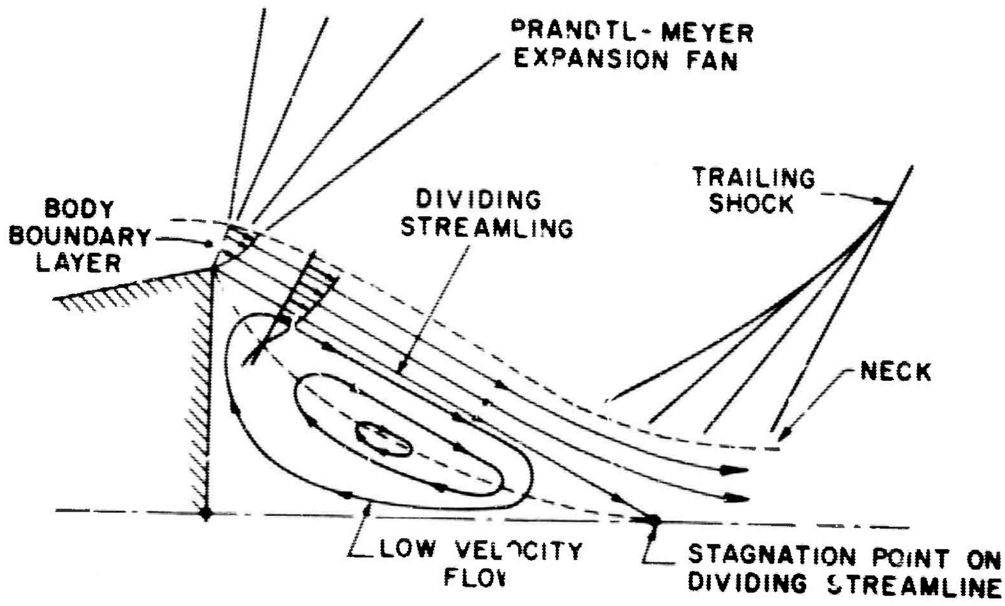
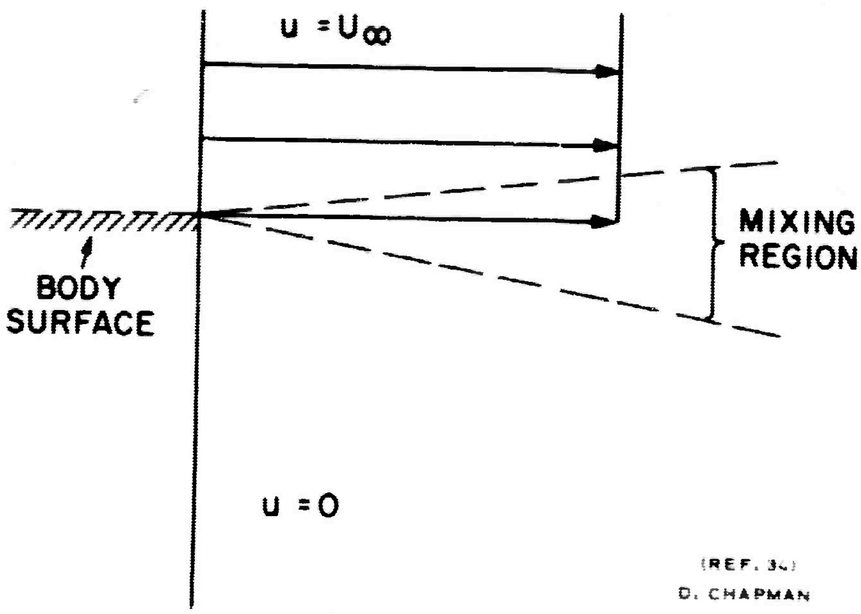


FIGURE 2



(a)



(b)

Fig. 1a - (a) Base Flow Region.

Fig. 1b - (b) Theoretical Mixing Model of Chapman for the Free Shear Layer.

FIGURE 3

EXPERIMENTAL WAKE ANGLES AND BASE PRESSURE RATIOS

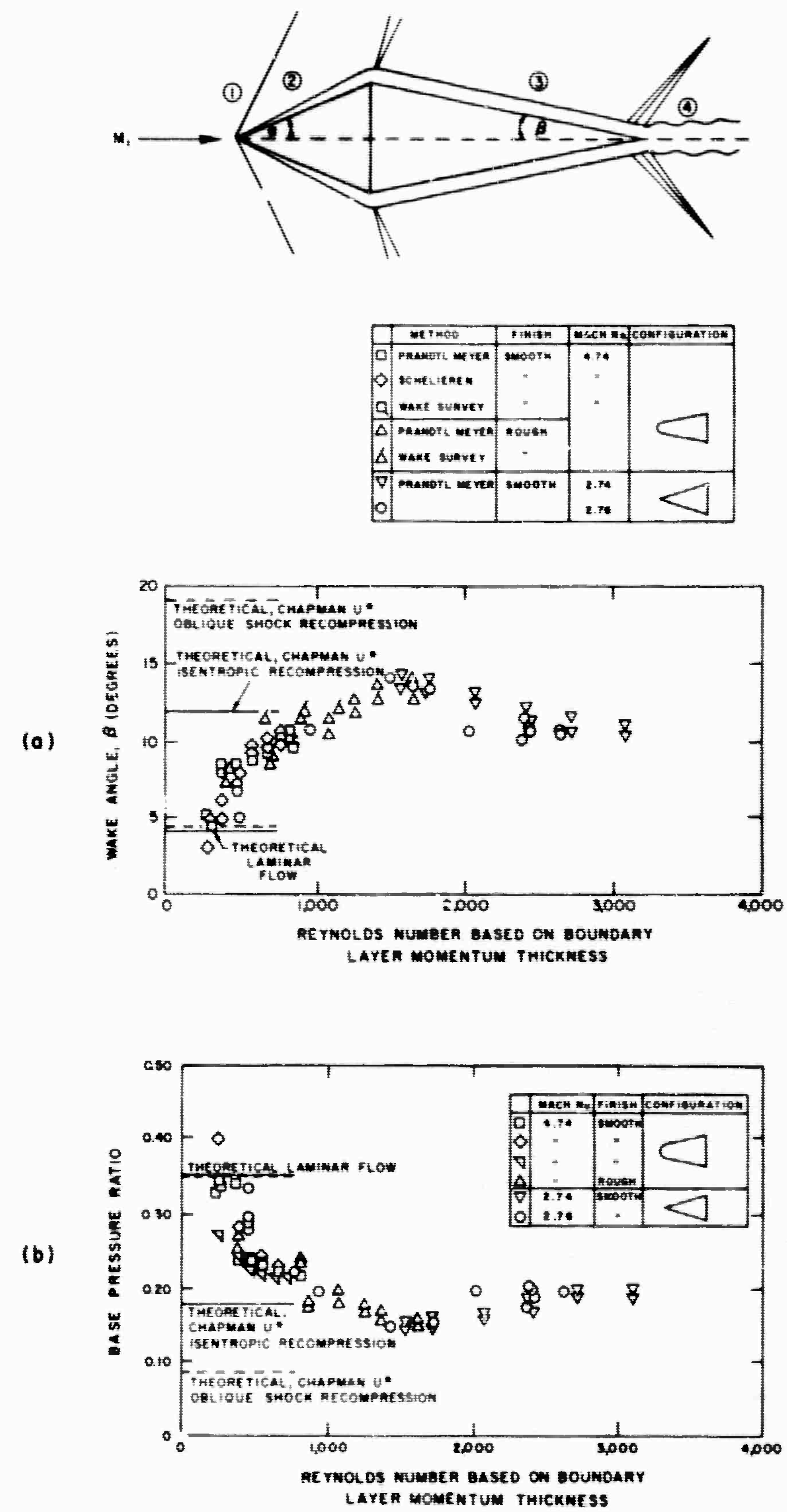
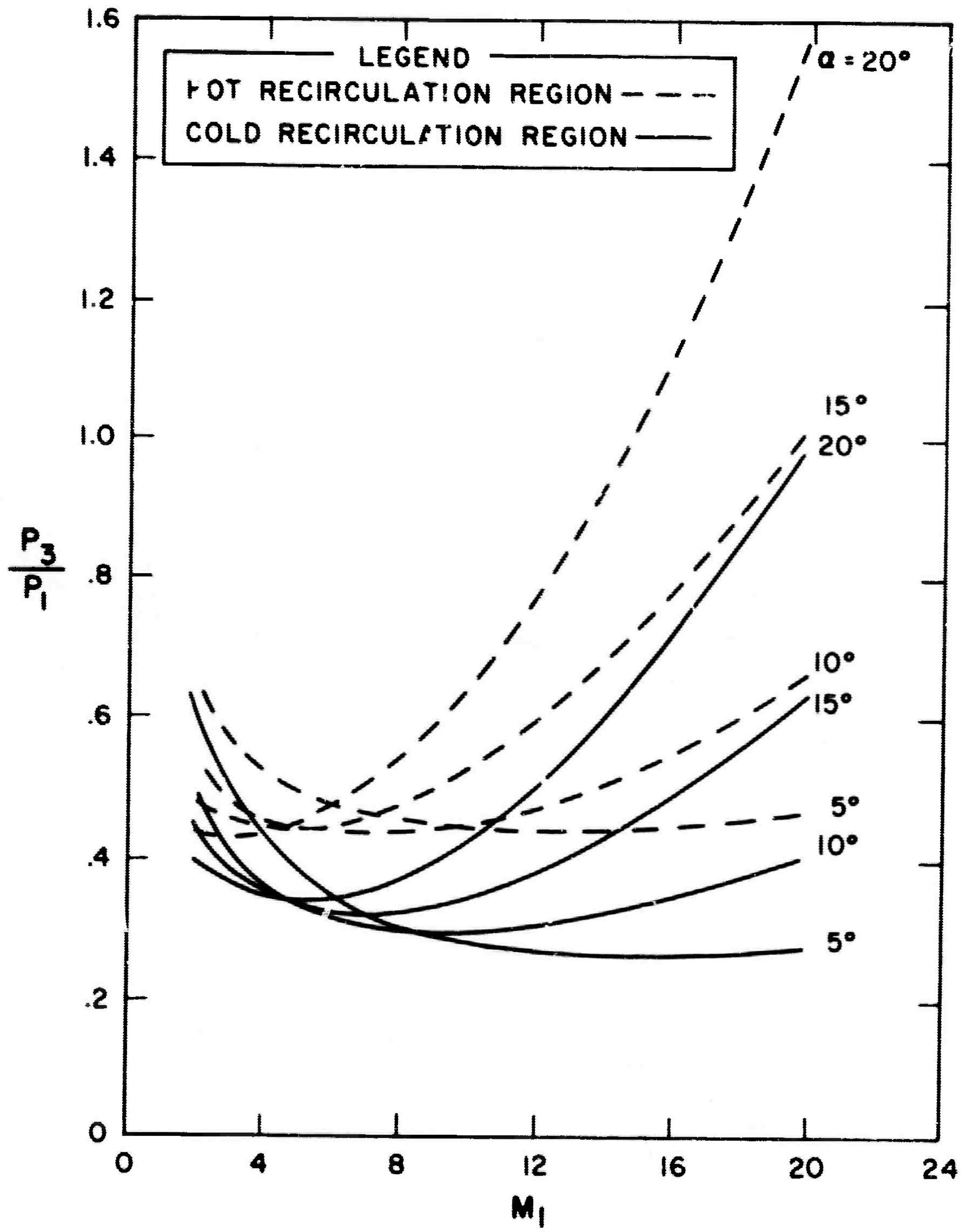


FIGURE 4

PRESSURE RATIO, P_3/P_1, FOR CONES $\gamma = 1.4$

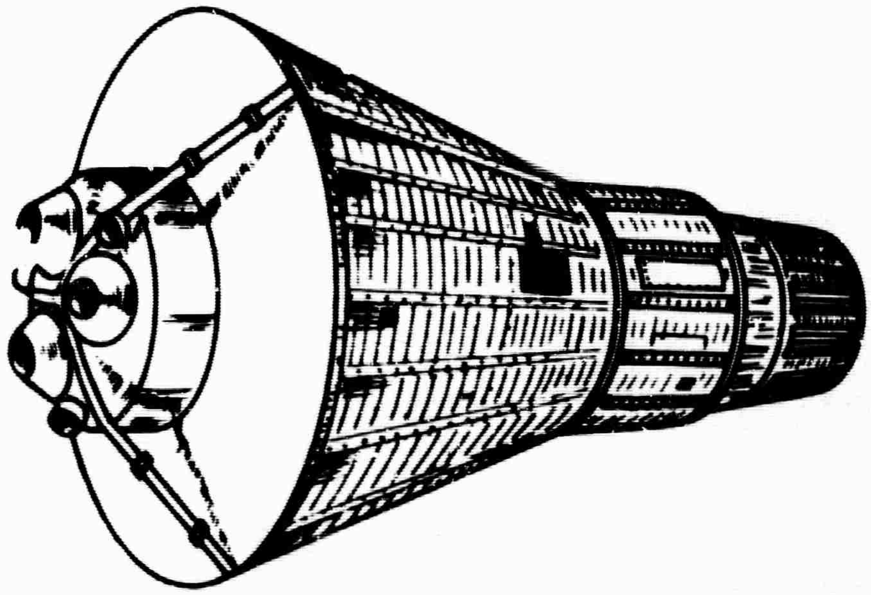


ELECTRO-OPTICAL SYSTEMS INC.

FIGURE 5

MERCURY SPACECRAFT CONFIGURATION

GENERAL CONFIGURATION WITH RETROPACKAGE



OVERALL DIMENSIONS (INCHES)

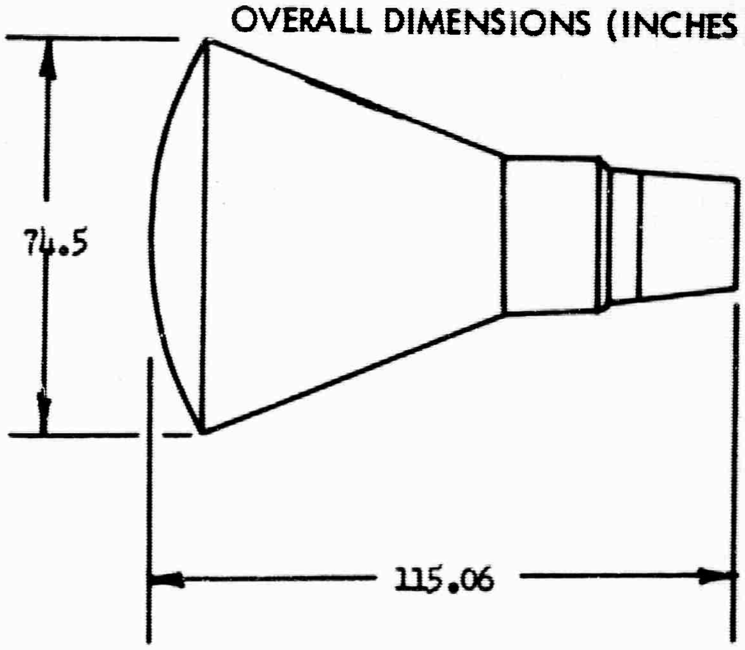
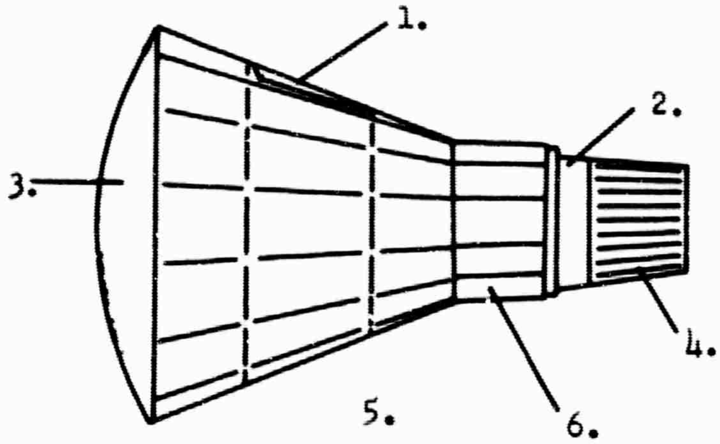


FIGURE 6

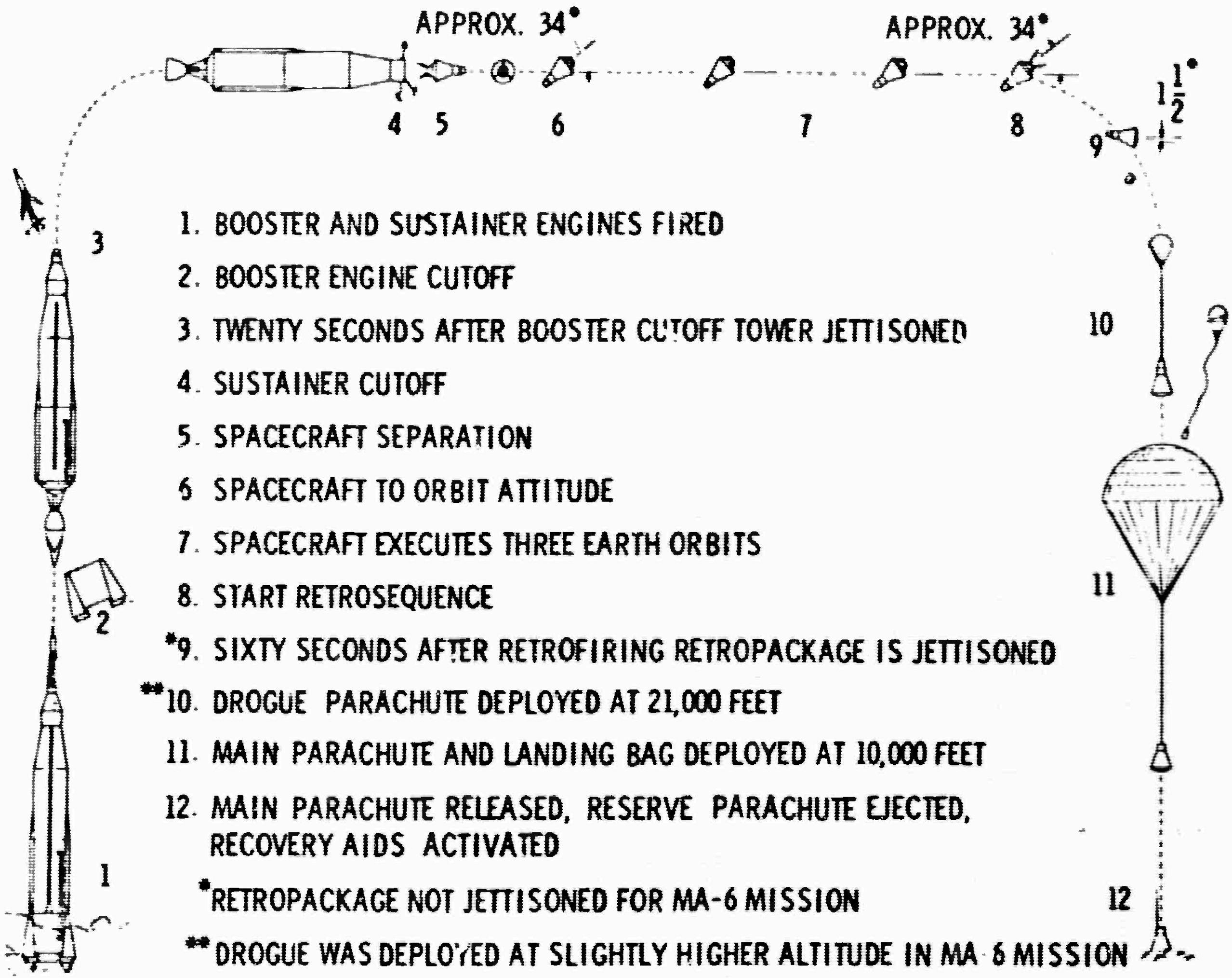
MERCURY SPACECRAFT SURFACE MATERIALS AND LOCATION



1.	Window	Vycor, Corning 7900
2.	Spacer	Vycor
3.	Heat shield	Fibreglass-phenolic resin
4.	Antenna fairing	René 41
5.	Shingles	René 41
6.	Shingles	Beryllium

FIGURE 7

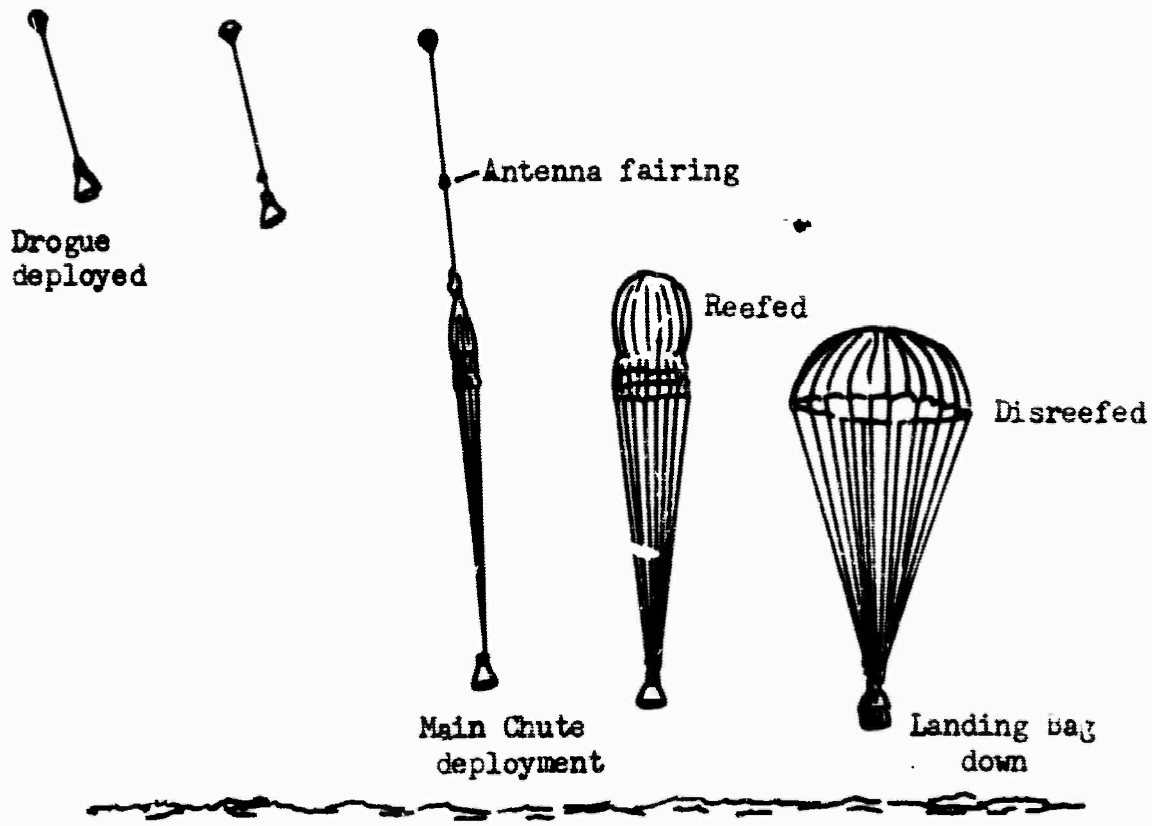
SEQUENCE OF MAJOR EVENTS IN THE MERCURY SPACECRAFT FLIGHT



FROM NASA REF 7

FIGURE 8

LANDING SEQUENCE



DETAIL OF LANDING BAG DEPLOYMENT

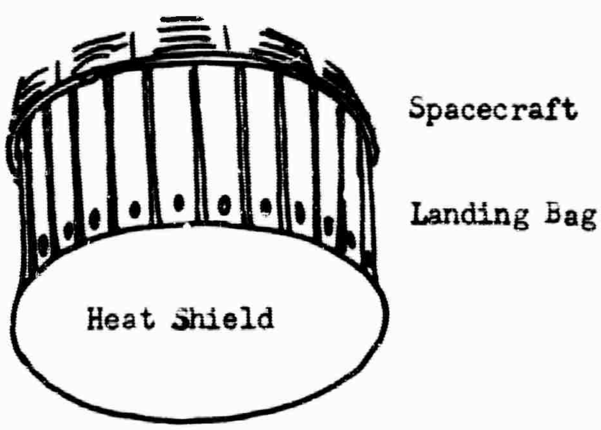
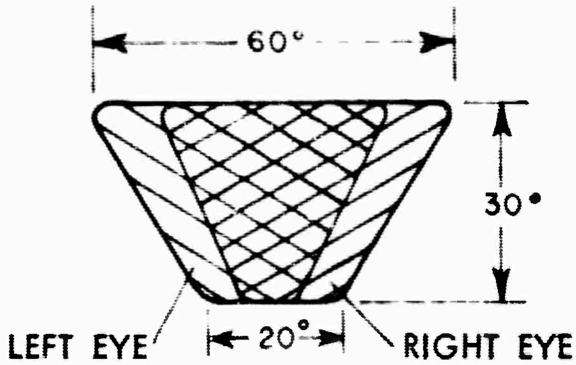
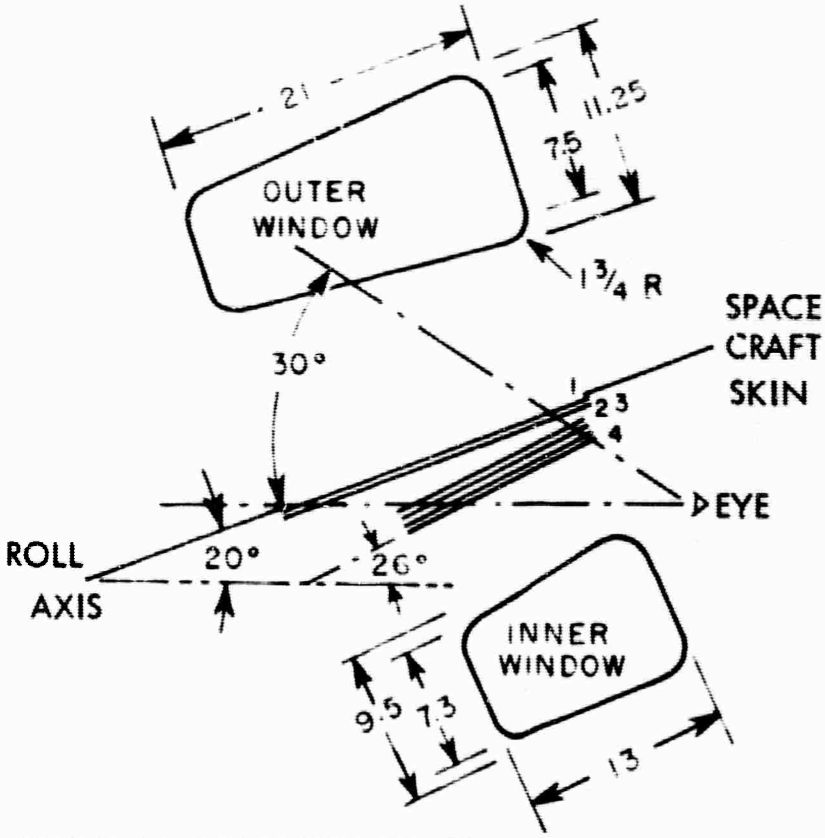


FIGURE 9

FIELD OF VIEW THROUGH THE MERCURY SPACECRAFT WINDOW

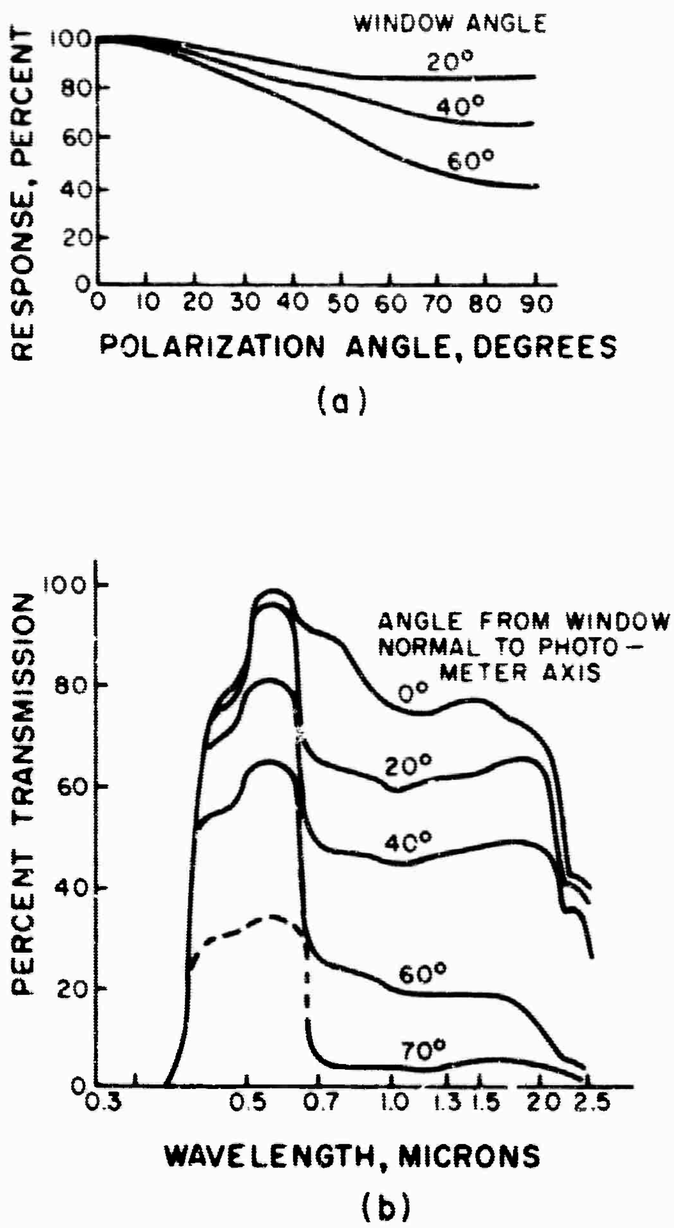


MERCURY SPACECRAFT WINDOW



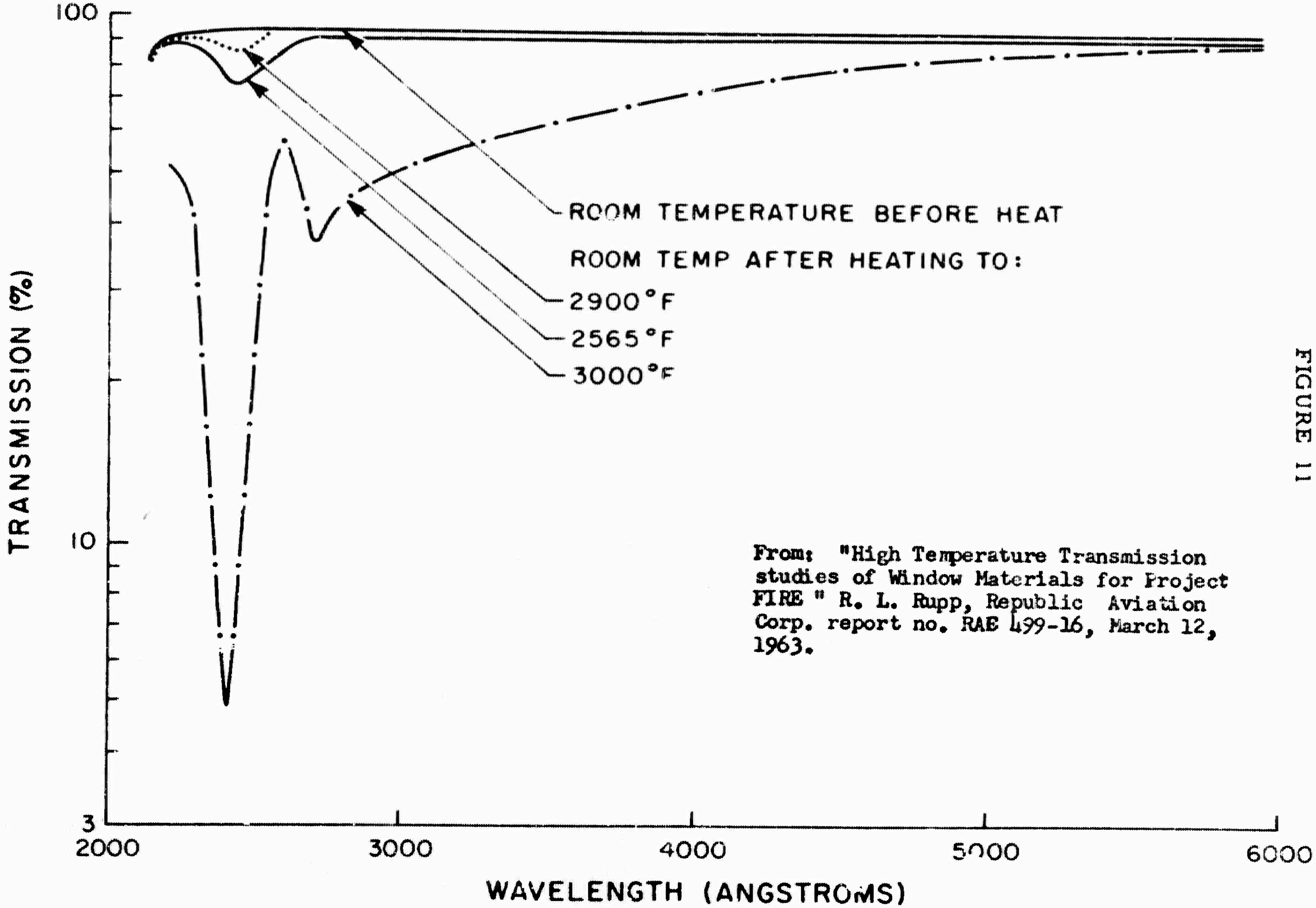
REDRAWN FROM NASA REF 10

FIGURE 10



REDRAWN FROM NASA REF 10

FIGURE 11



From: "High Temperature Transmission studies of Window Materials for Project FIRE" R. L. Rupp, Republic Aviation Corp. report no. RAE 499-16, March 12, 1963.

FIGURE 12

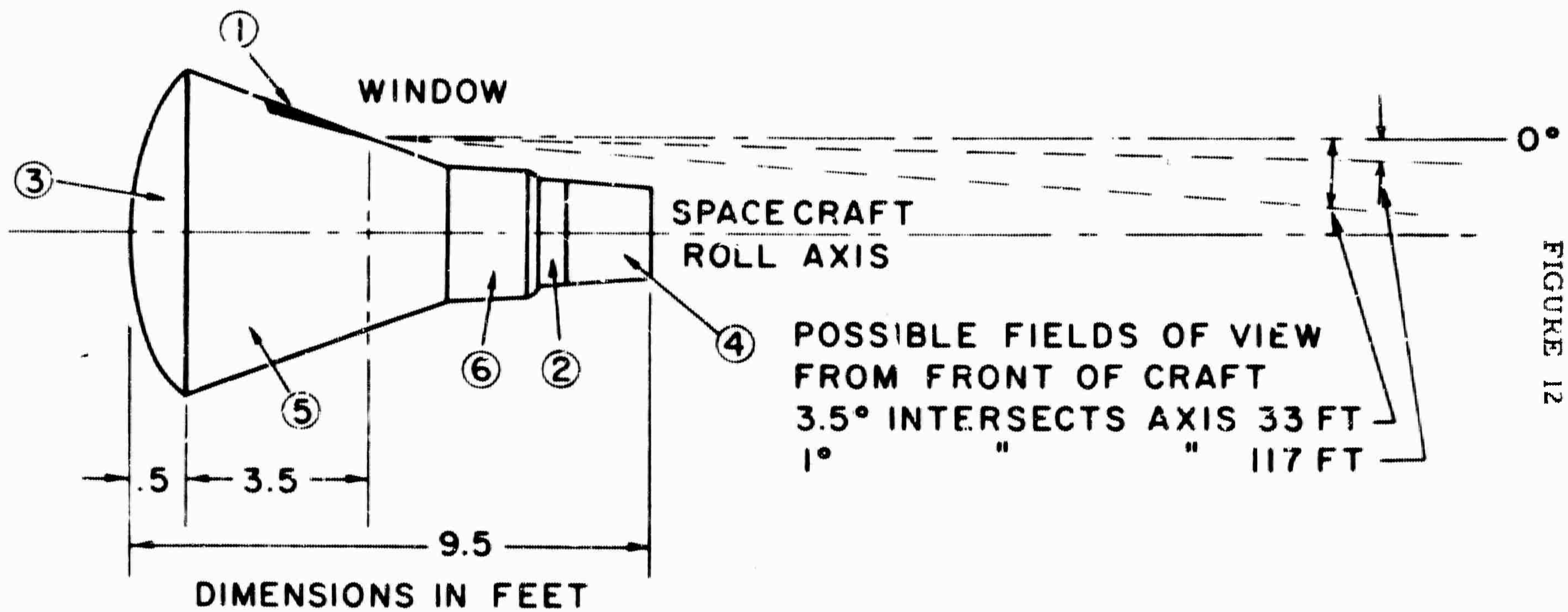


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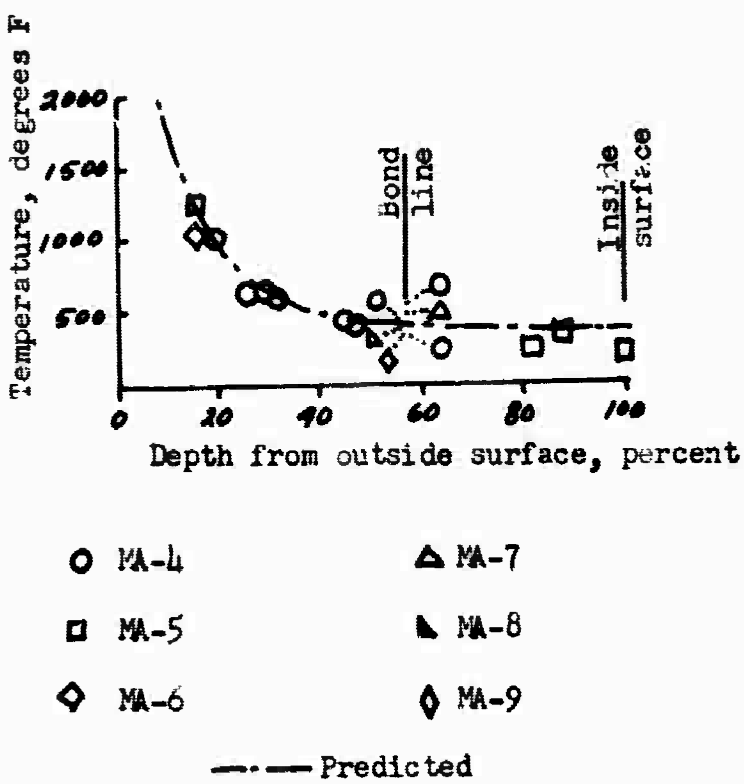
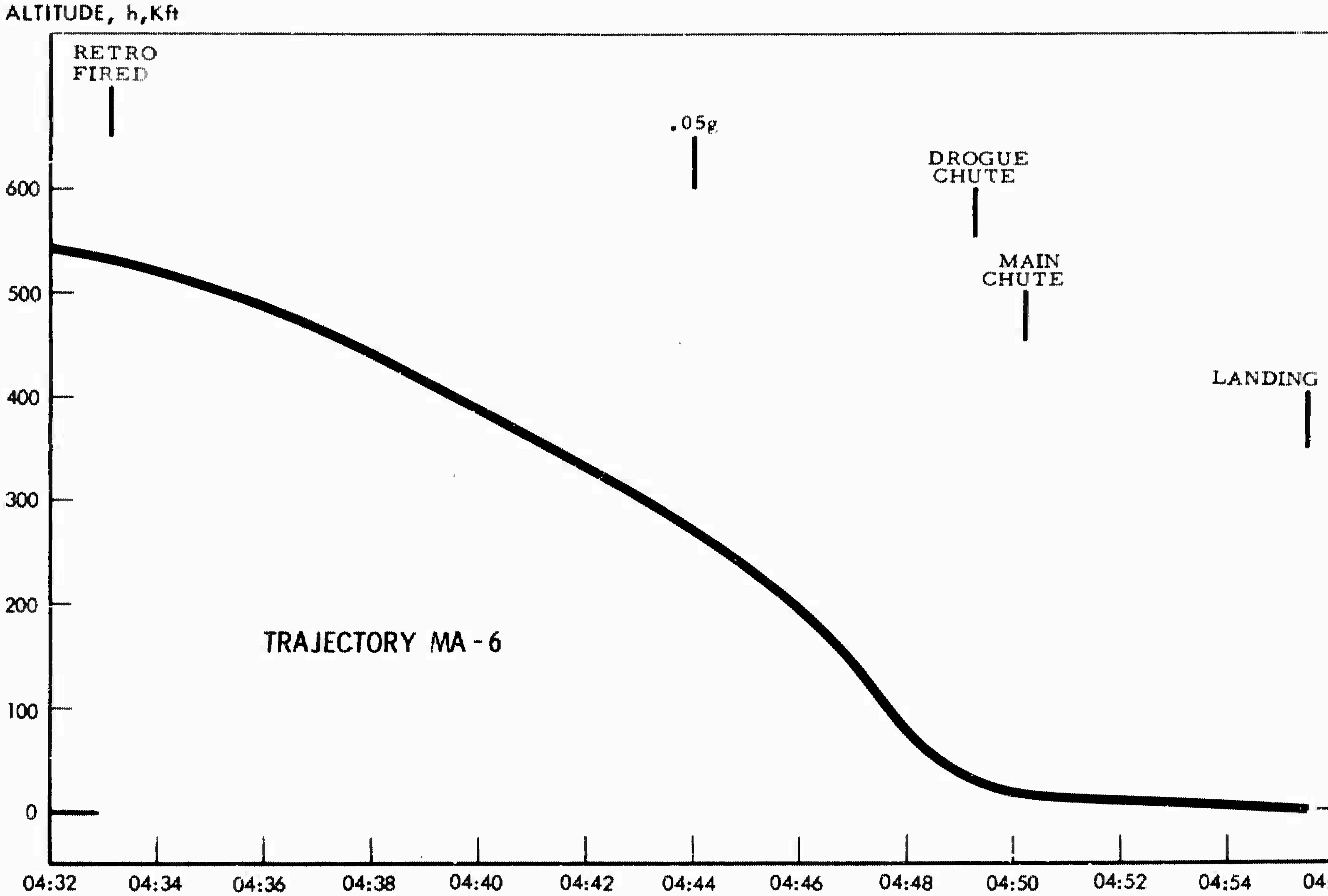
FIGURE 13

SPACECRAFT HEATSHIELD TEMPERATURE RESPONSE - MAXIMUM TEMPERATURES



From: Mercury Project Summary Including the Results of the Fourth Manned Orbital Flight, NASA SP-45, October 1963.



MA-6

FIGURE 14

FIGURE 15

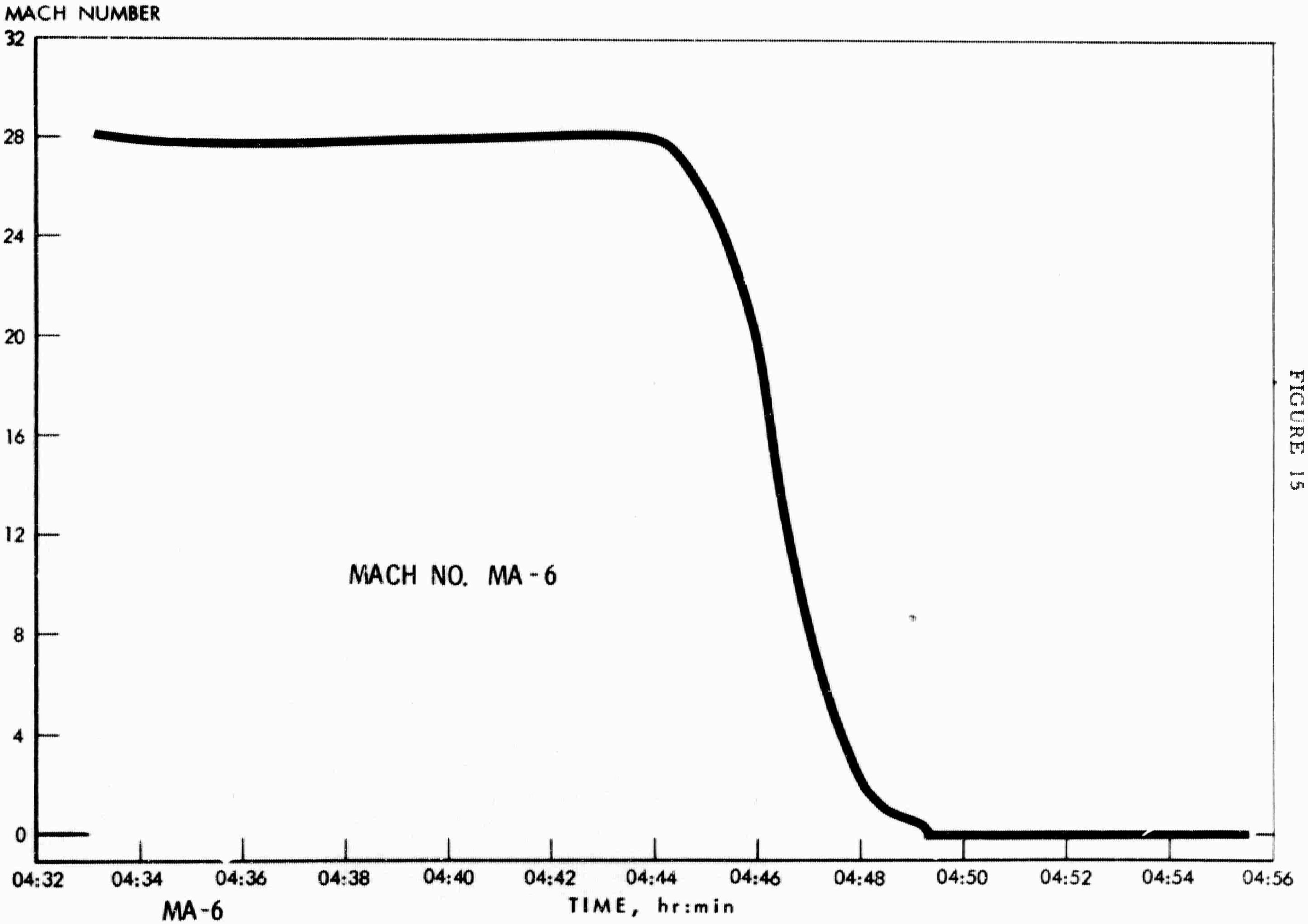


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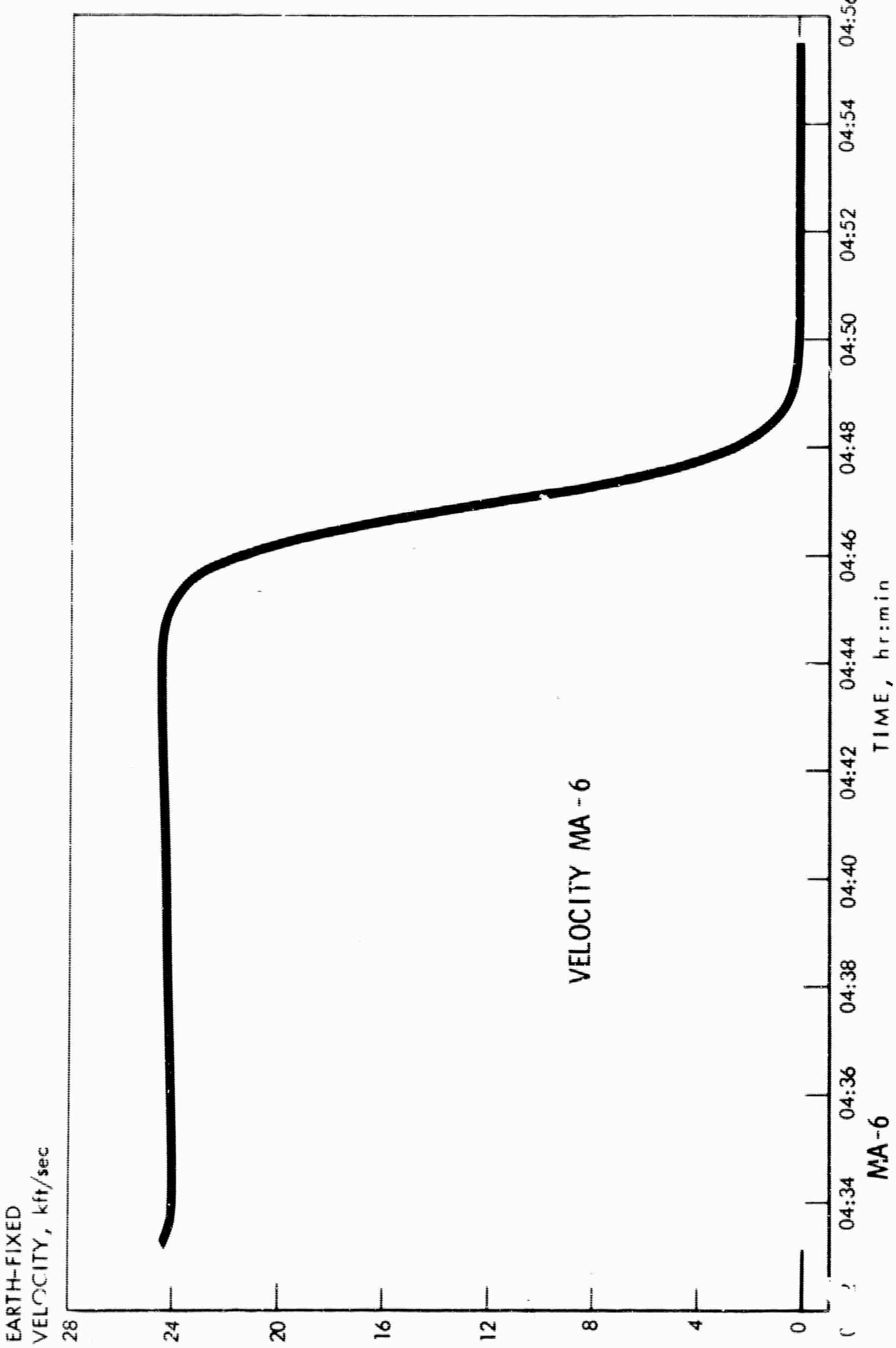
FIGURE 16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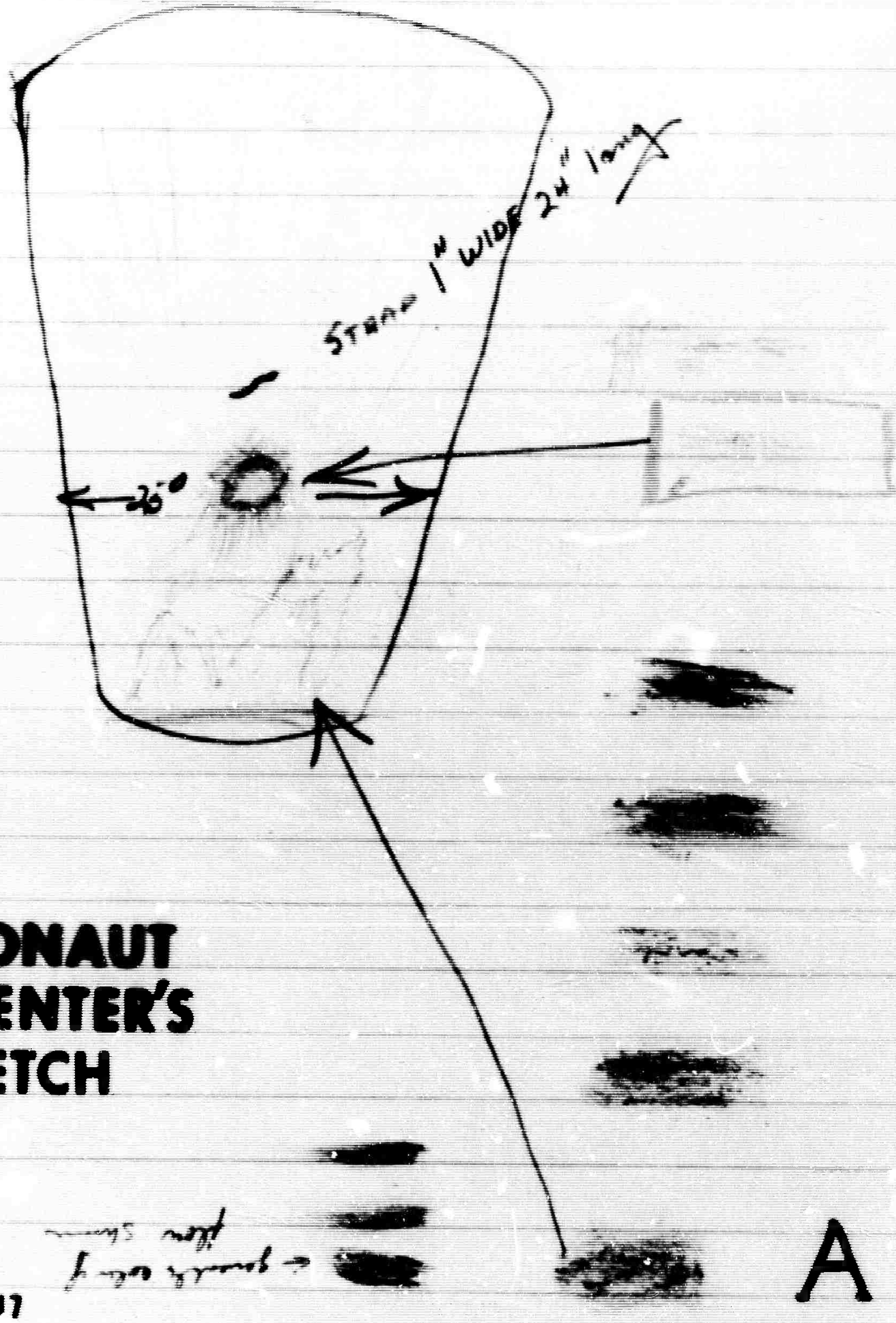
VELOCITY MA-6
MA-6



ASTRONAUT CARPENTER'S SKETCH

FIGURE 17

NOTE THAT ASTRONAUT SCHIRRA AGREED AS TO THE GENERAL STRUCTURE OF THE EFFECT BUT SAW ALL OF IT IN THE COLOR INDICATED AT "A" IN THE SKETCH

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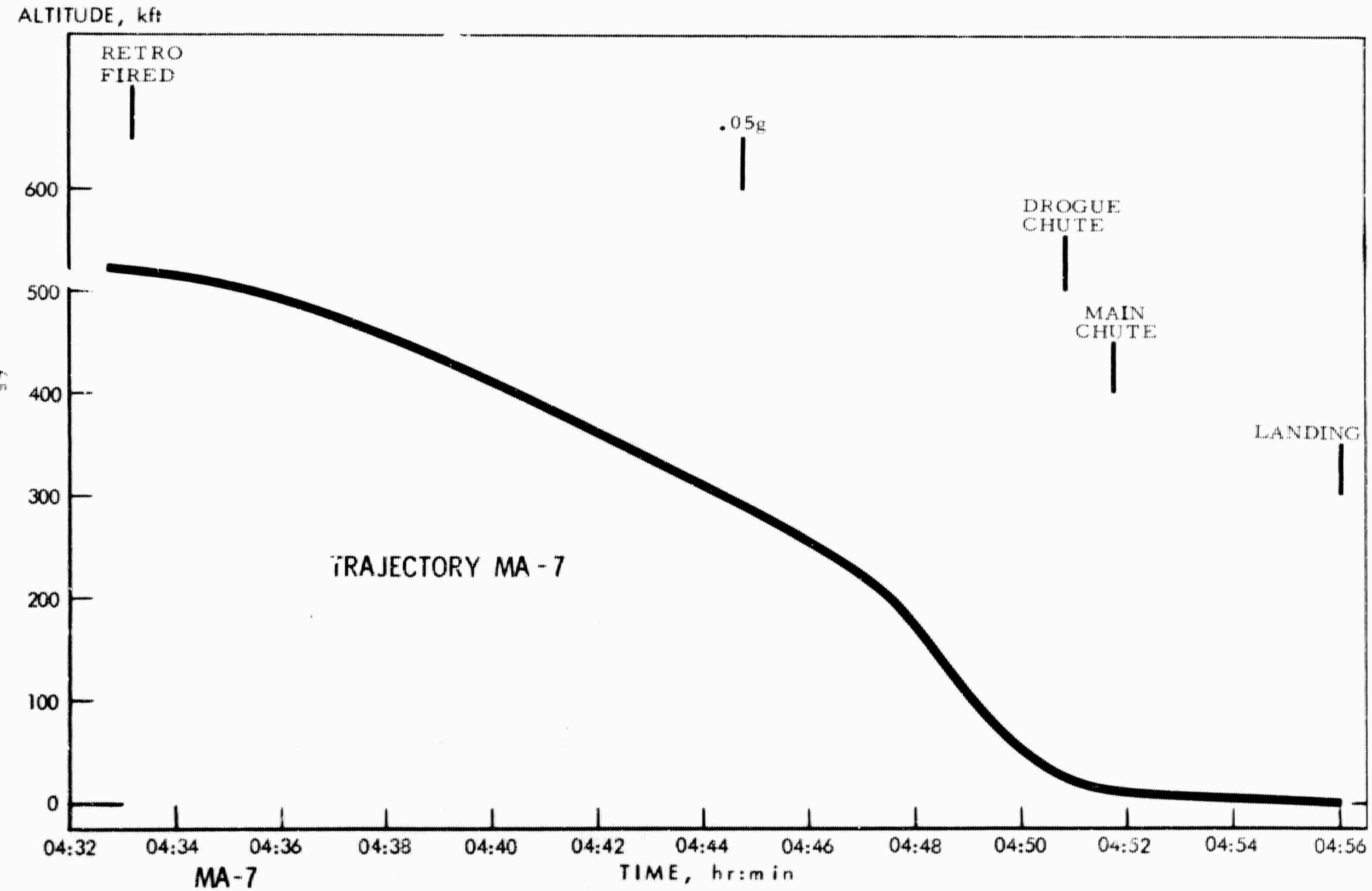
FIGURE 18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MAIN CHUTE
LANDING
TRAJECTORY MA - 7
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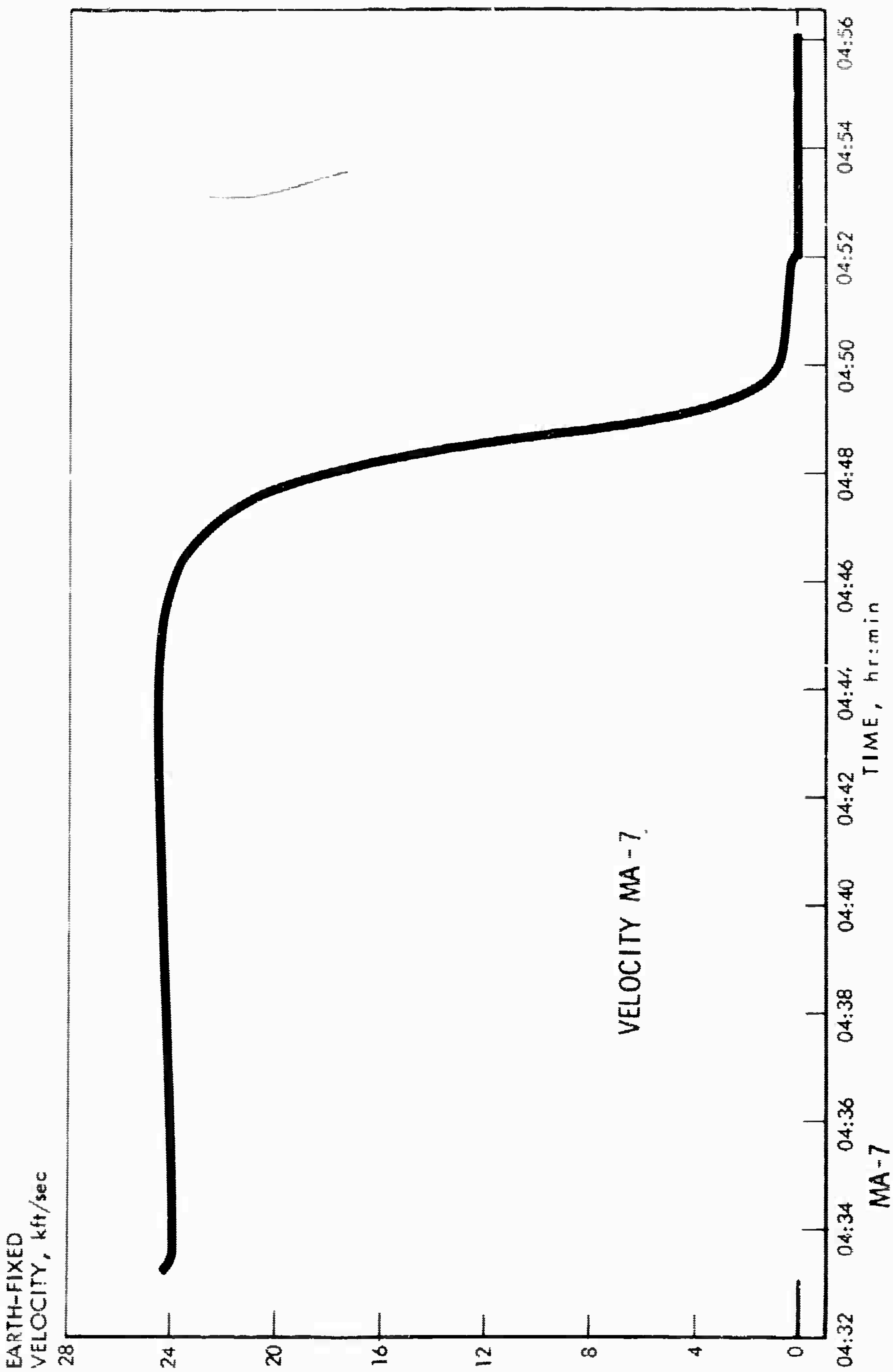
TIME, hr:min
MA-7

FIGURE 19



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TIME, hr:min
VELOCITY MA-7
MA-7

FIGURE 20

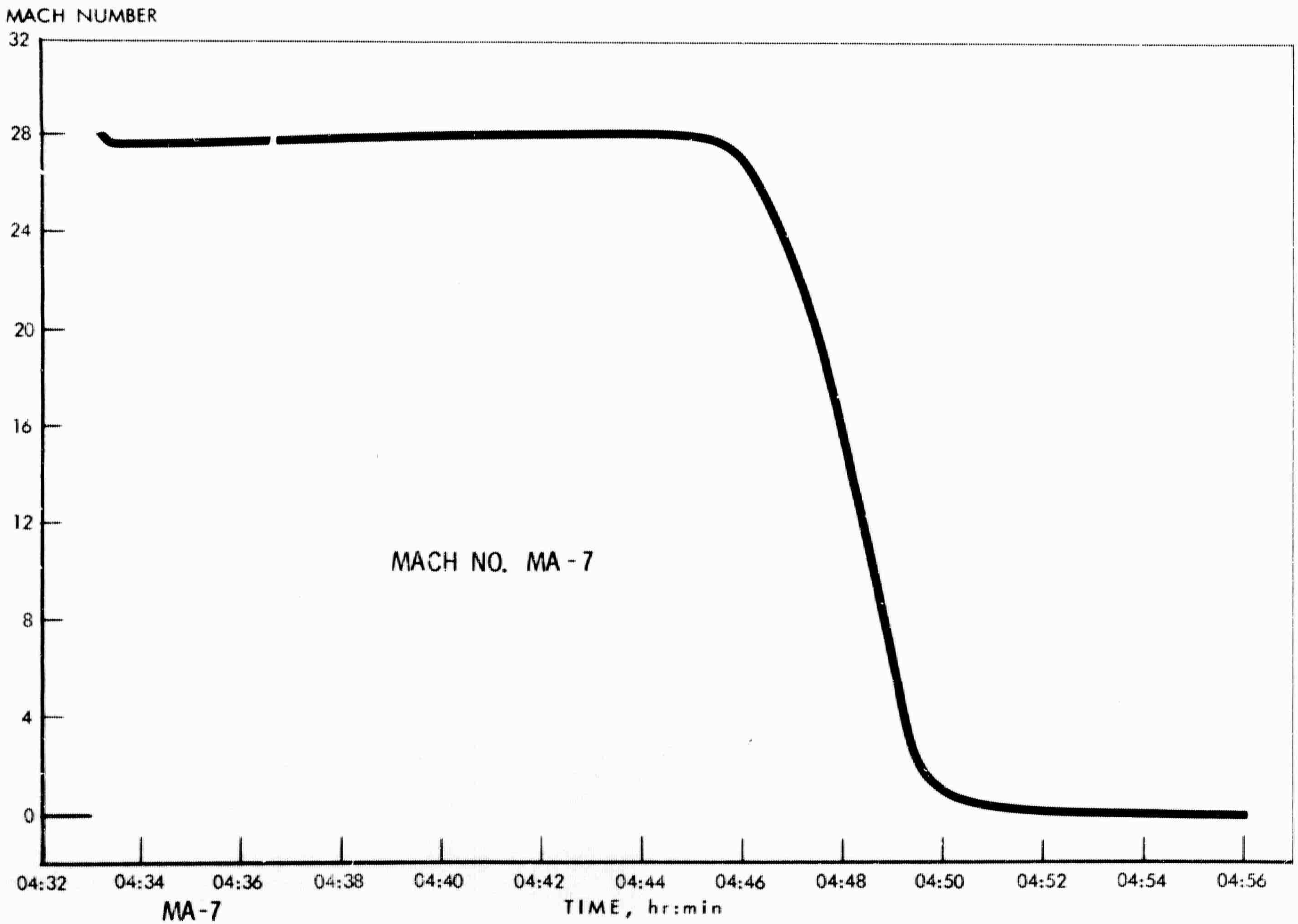
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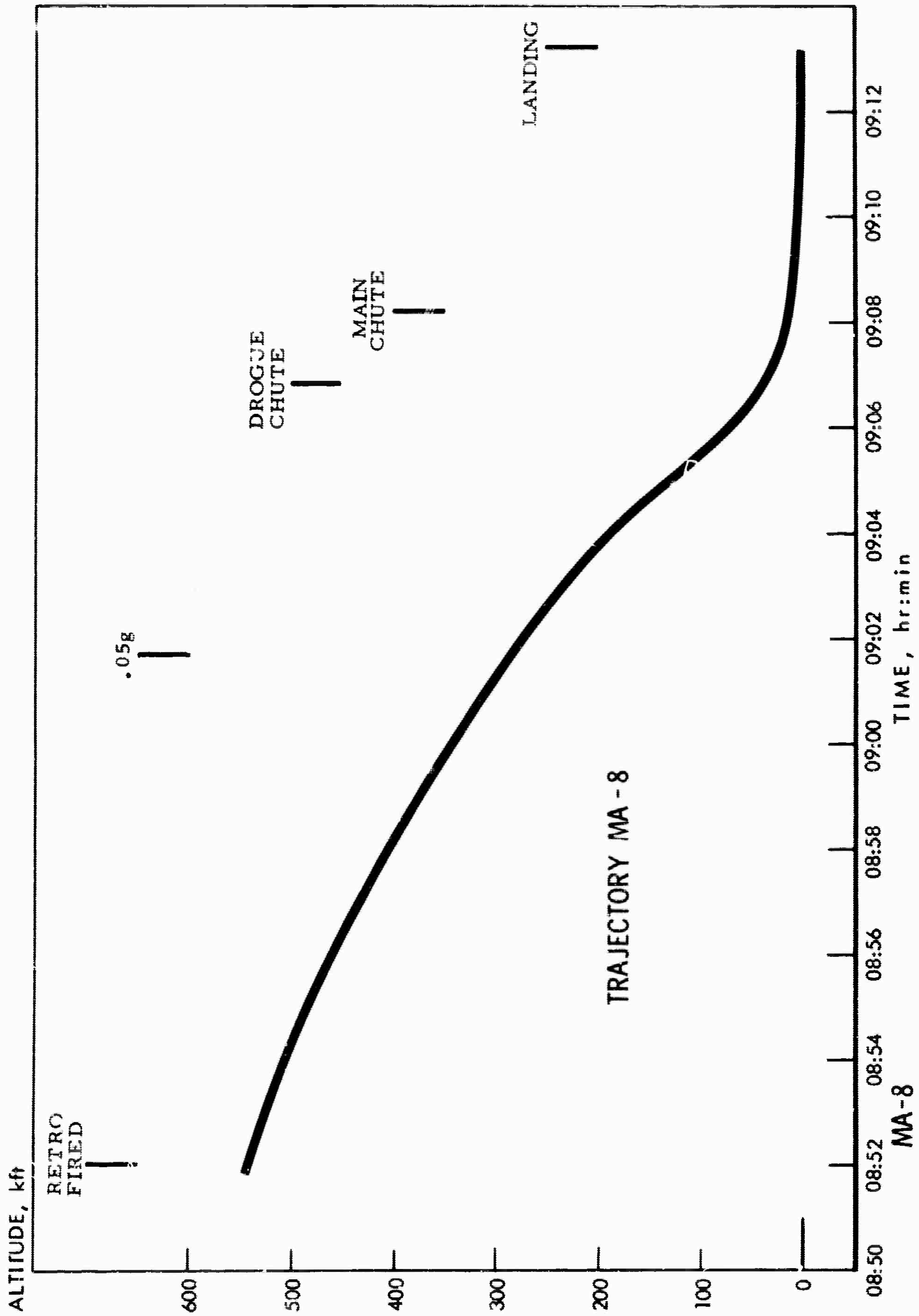
FIGURE 21



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RETRO FIRED
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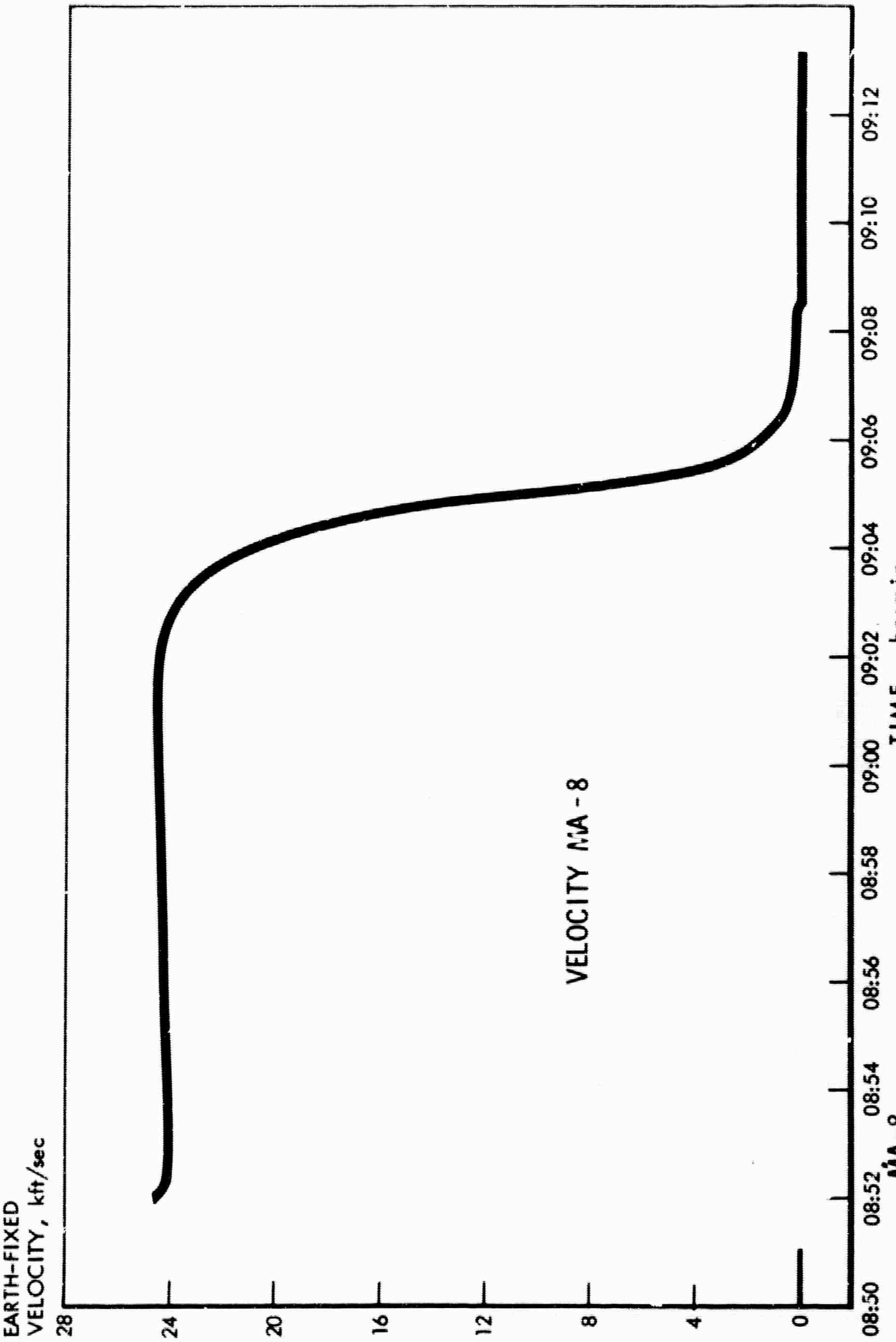
DROGUE CHUTE
MAIN CHUTE
LANDING
TRAJECTORY MA-8
MA-8

FIGURE 22



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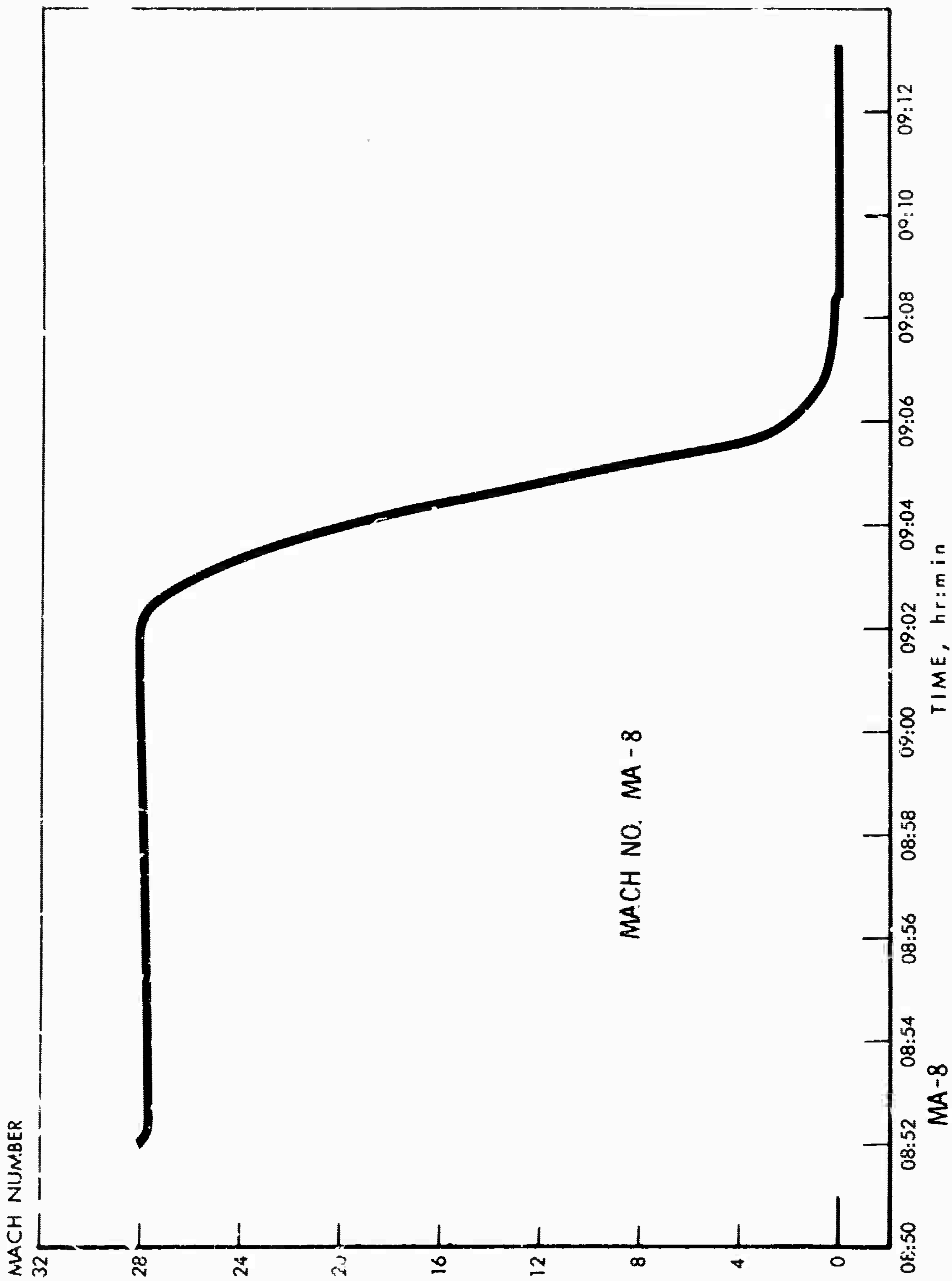
TIME, hr:min
VELOCITY MA-8
MA-8

FIGURE 23



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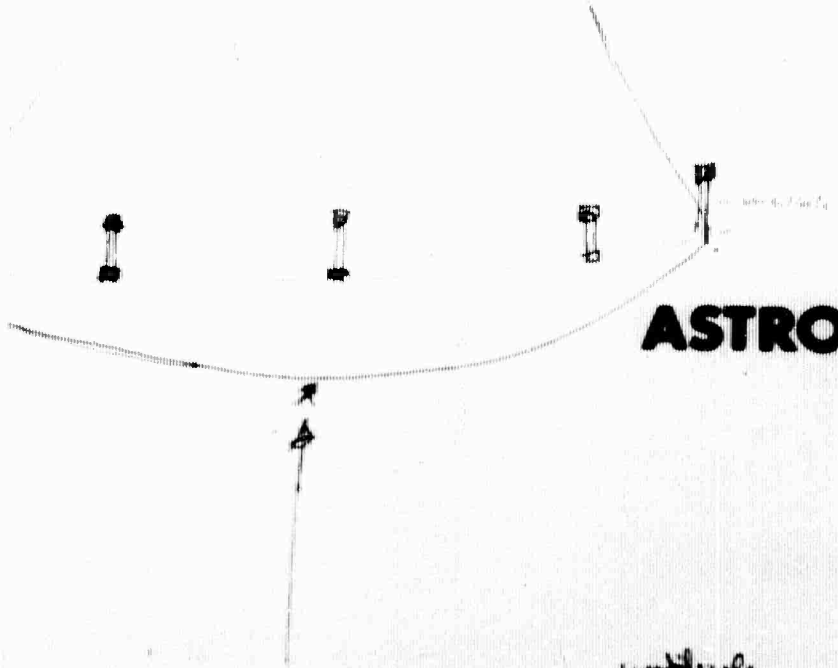

ASTRONAUT COOPER'S SKETCH

1. FF glow - orange - then a feeling of heating
2. Wake starting 15 20 ft behind
3. Fireball
4. Re green glow - more greyish
5. Particles streaming off
6.

Strap started heating - fell down about white hot, then burned into

umbilical strap hung over window, then hung in there

34:05

34:05 - Shock wave

34:08 - Glow

34:15 - Brown cast

34:13 - 55 sec

Wake prior to Magee

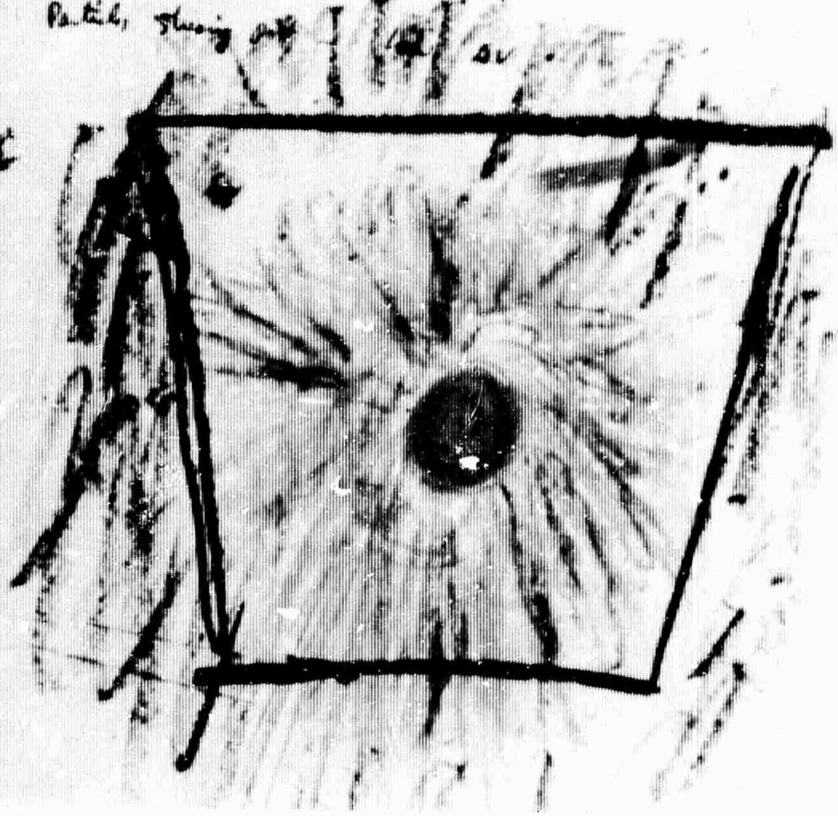

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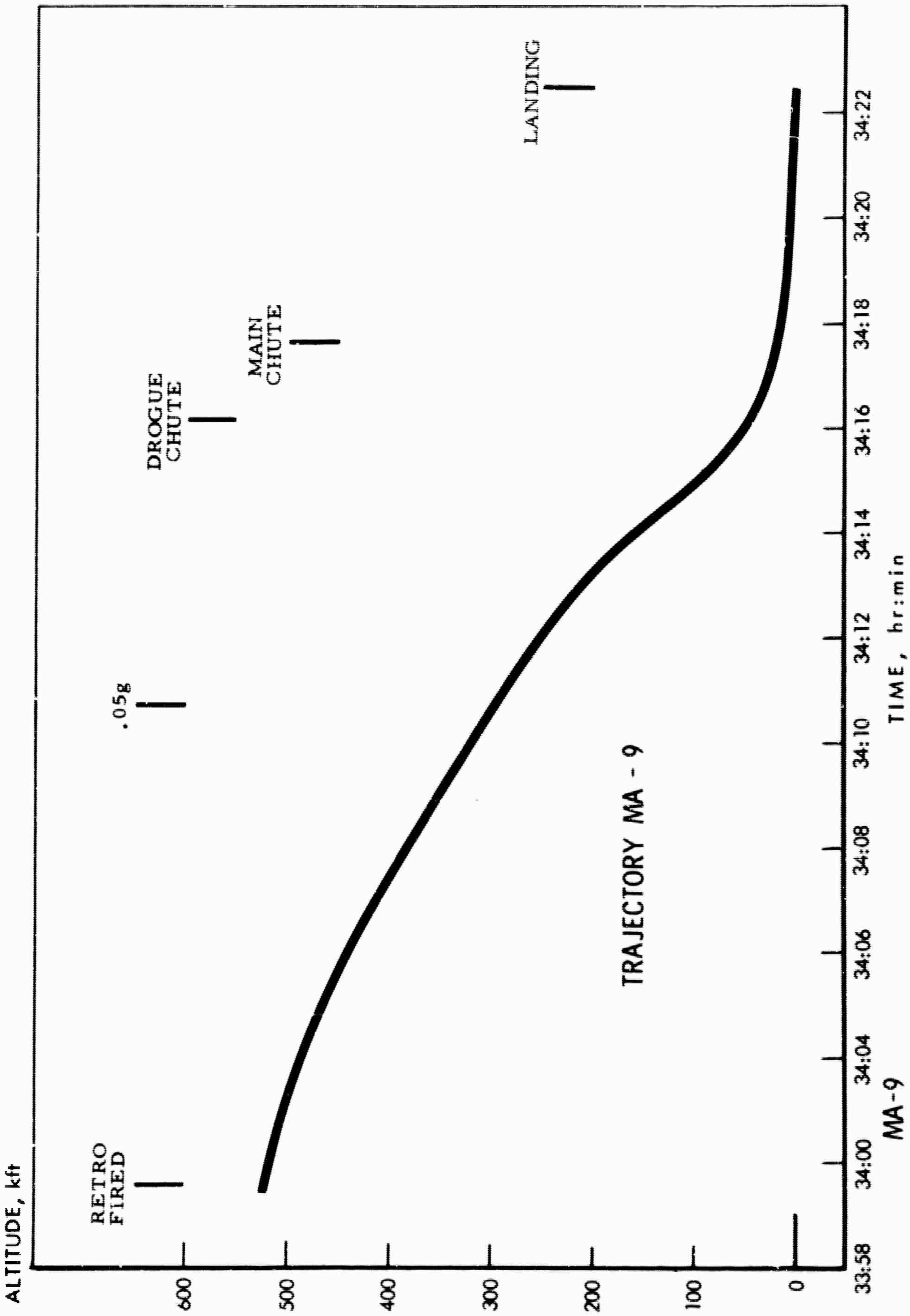
FIGURE 25



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34:20
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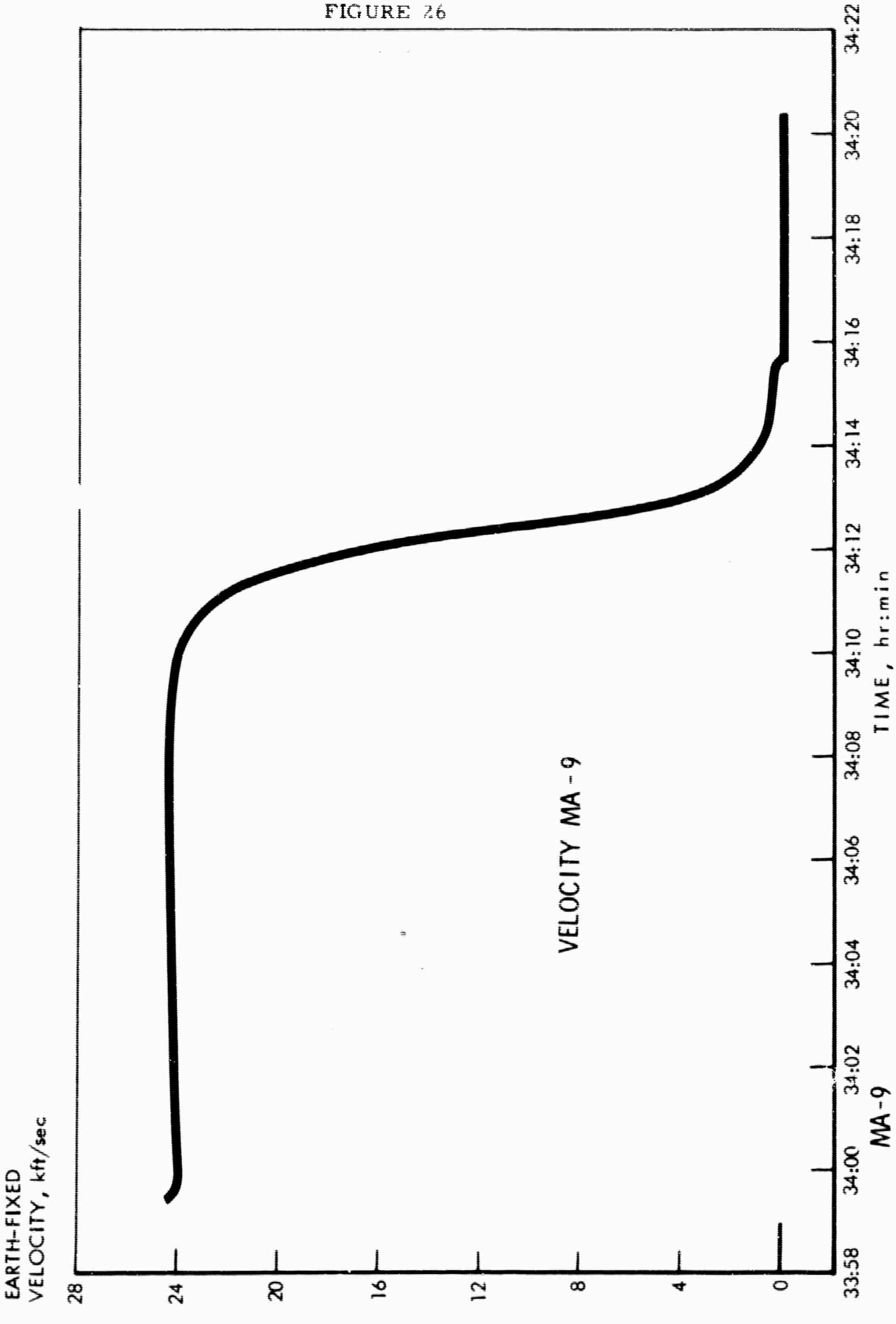
TIME, hr:min
RETRO FIRED
.05g
DROGUE CHUTE
MAIN CHUTE
LANDING
TRAJECTORY MA - 9
MA-9

FIGURE 26



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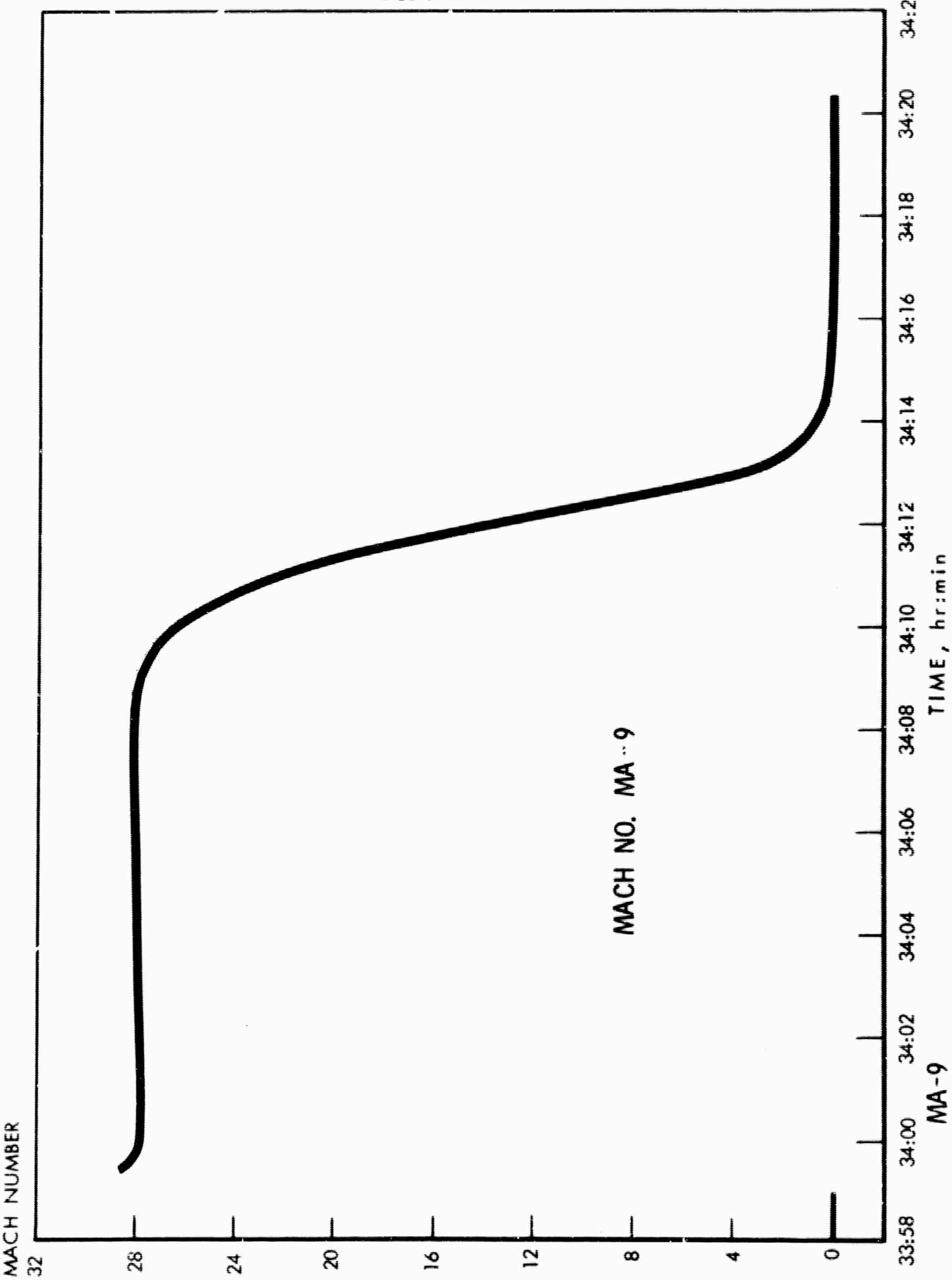
VELOCITY MA - 9
MA-9

FIGURE 27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